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HQP-485-35 VOLUME SUPP. "A"

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MUNICIPALITY: OTTAWA VRS
FILE NUMBER: HQ-485-35
VOLUME: SUPP A
CAPTION:
OPERATION MORNINGLIGHT

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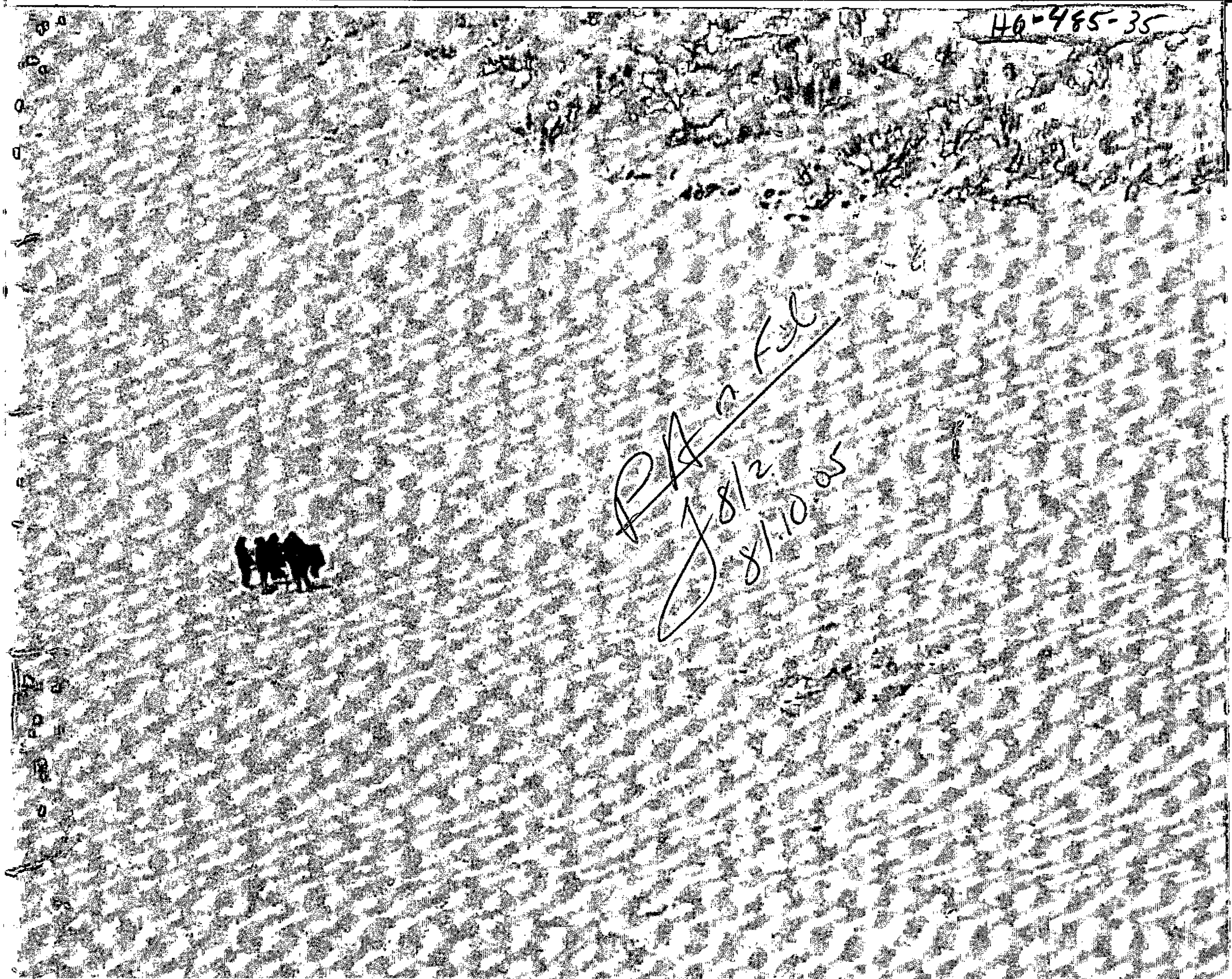
COSMOS 954

THE OCCURRENCE AND NATURE OF RECOVERED DEBRIS



Atomic Energy Control Board
Commission de contrôle de l'énergie atomique

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COVER

The cover photograph shows the location of the assemblage of rods, later dubbed the "antlers", encountered on the Thelon River by members of a group of six men who were camping for the winter at Warden's Grove. This location is approximately 500 km north-easterly from Yellowknife, and represents the farthest east identification of Cosmos 954 debris. The photograph shows the obvious crater where the antlers were found; this crater is not an impact phenomenon but represents melting of the surface snow and ice by the heat of reaction of lithium hydride (which filled the control tubes) with melted snow. One can see the effects of spatter from the "crater" for some distance on all sides, and an elongated stain on the snow.

The photograph also shows the general nature of the land at the time when Cosmos 954 re-entered. Where there are trees, or scrub brush as in this picture, some topographical expression is visible, but otherwise land and water appear much the same, exhibiting only a wind-textured hard surface.

The area lies partly in Canada's zone of discontinuous permafrost (mean air temperature between -4°C and -8°C). It also overlaps the open woodland zone and the more northern forest-tundra zone. The environment of the area may be categorized as subarctic/boreal. Whatever the names and technical terms, the search area in winter is a most inhospitable place. With few exceptions such as in fast running rivers, all water is covered with ice feet thick, all ice and land is covered with snow which although not reaching the depths recorded in higher precipitation areas to the south nevertheless blankets everything and disguises or masks most summertime landmarks, and over all a piercing wind may blow, introducing a chill factor that may make the equivalent temperature as low as -100°C. Under these conditions mechanical equipment does not always function. At this particular spot, the first technical search group was forced to spend a night under survival conditions when their helicopter failed to start.

In winter, the land is stark, or starkly beautiful, depending on viewpoint, and it offers a real challenge to people from farther south. In the summer wild rivers and abundant lakes present another challenge that is being more and more taken up by those interested in getting back to nature, or in following the incredible footsteps of early explorers of the north. The summer growing period however, is squeezed into a period of about half that of the Toronto latitude. Flora and fauna must be tough to survive; their ecological equilibrium tends however to be susceptible to outside influences and slow to recover.

This was the locale of the Cosmos 954 search and recovery operations.

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COSMOS 954

The Occurrence and Nature

of

Recovered Debris

by
W.K. Gummer,
F.R. Campbell,
G.B. Knight,
J.L. Ricard

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Summary

The Russian nuclear-powered satellite, Cosmos 954, re-entered the earth's atmosphere early on 24 January, 1978, watched first by the tracking instruments of NORAD and then by the startled eyes of a few residents of the Northwest Territories. Concern about radioactive debris, whose presence was quickly verified on the frozen surfaces of lakes and land, led to a massive airborne and ground search and recovery program that lasted from re-entry date to the middle of October, 1978, interrupted only by the spring break-up period. The search area extended from Great Slave Lake northeastward towards Baker Lake.

Only about 65 kilograms of material were found, although it is probable that the satellite weighed several tons. All fragments but one — itself weighing over 18 kg — were radioactive; many showed clear evidence of melting and erosion. A few were extremely radioactive and could under certain conditions have caused serious effects on people, even death. In addition to the obvious fragments that fell along a well-defined track nearly 600 km in length, a wide area stretching southwards from Great Slave Lake was affected by a scattered shower of minute particles representing the enriched fuel of the satellite's power source, with a highly variable density perhaps averaging a few hundred per square kilometre. Because of their radioactivity and of public concern about the hazards that might be presented by contamination of water supplies, or by pick-up of particles by clothing, for example, intensive searches were carried out in the Territories and adjacent Alberta and Saskatchewan, in frequented areas such as towns, roads, fishing and hunting camps in an effort to find and remove as much as possible of such material.

Laboratory studies were carried out on particles to learn their chemical and physical nature, in order to understand their probable behaviour in the general environment.

Search and recovery continued until it could be concluded that 1) it was most unlikely that highly radioactive fragments had been missed; 2) all obvious large fragments had been located and removed; 3) the risk to people from particles remaining in unfrequented areas was not great because of the particles' tiny size, their general insolubility, and their scattered distribution. Residual radiological risks were also fading rapidly relative to the natural radiation background.

Sommaire

La rentrée spectaculaire dans l'atmosphère du satellite nucléaire soviétique Cosmos 954, au-dessus des Territoires du Nord-Ouest, tôt le matin du 24 janvier 1978, a été vue par quelques-uns des habitants après avoir été repérée d'abord par les systèmes de NORAD. D'importants travaux de dépistage et de recouvrement des débris radioactifs furent entrepris dès que leur présence au sol fut déterminée. Ces travaux se sont poursuivis jusqu'au dégel du printemps et par après, jusqu'à la mi-octobre à partir du Grand Lac des Esclaves et dans une direction nord-est vers le lac Baker.

Même si le poids du satellite était probablement de plusieurs tonnes, seulement 65 kilogrammes environ de matériel furent récupérés. Sauf pour une pièce pesant 18 kilogrammes, tous les fragments récupérés étaient radioactifs; plusieurs avaient dû fondre et étaient corrodés. Les plus fortement radioactifs présentaient un danger pour la santé des personnes et dans certaines circonstances, même la mort. En plus des fragments récupérés dans le couloir de rentrée du satellite, long de quelques 600 kilomètres, des milliers de petites particules provenant du combustible enrichi du réacteur, furent dispersées sur une grande surface au sud du Grand Lac des Esclaves. La distribution de ces particules variait considérablement mais en moyenne elle était de quelques centaines par kilomètre carré. Vu les risques de contamination de l'eau d'approvisionnements et d'irradiation externe par des particules radioactives logées dans les vêtements, des recherches intensives furent menées dans les villes, sur les routes et autres endroits fréquentés tels les camps de pêche et de chasse situées dans les Territoires du Nord-Ouest et les provinces avoisinantes de l'Alberta et la Saskatchewan, dans le but d'en récupérer le plus grand nombre.

Les particules récupérées ont été étudiées en laboratoire pour établir leurs propriétés physiques et chimiques et en déterminer les effets possibles sur l'environnement.

Le dépistage et le recouvrement furent poursuivis jusqu'à ce que les autorités soient satisfaites d'avoir repéré et recouvré tous les fragments de taille importante et ceux qui étaient hautement radioactifs. Il était alors possible de conclure que le risque pour les personnes dans les régions peu fréquentées n'était pas grand en raison de la petite taille des particules, de leur insolubilité et de leur faible concentration. Étant donné que la radioactivité décroit avec le temps, son niveau se rapproche rapidement du niveau de la radioactivité naturelle.

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List of Abbreviations and Acronyms

AECB	Atomic Energy Control Board
AECL	Atomic Energy of Canada Limited
CWS	Canadian Wildlife Service
DFE	Dept. of Fisheries and the Environment
DND	Dept. of National Defence
EA	Dept. of External Affairs
EMR	Dept. of Energy, Mines and Resources
GSC	Geological Survey of Canada
ICRP	International Commission on Radiological Protection
INA	Dept. of Indian and Northern Affairs
NAST	Nuclear Accident Support Teams (DND)
NEST	Nuclear Emergency Search Team (USA)
NHW	Dept. of National Health and Welfare
NORAD	North American Air Defence
NRC	National Research Council
NWT	Northwest Territories
RCMP	Royal Canadian Mounted Police
RPB	Radiation Protection Bureau
USSR	Union of Soviet Socialist Republics
WNRE	Whiteshell Nuclear Research Establishment

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COSMOS 954

The Occurrence and Nature of Recovered Debris

1. Introduction

Cosmos 954, a Russian nuclear-powered satellite, re-entered the earth's atmosphere early in the morning of 24 January, 1978. Telescopic camera reports from Hawaii indicated that the satellite, glowing from the friction of re-entry, and breaking up, was headed towards northern Canada over the Queen Charlotte Islands. Shortly thereafter, visual sightings in the Yellowknife area, Northwest Territories (NWT), confirmed that an unknown quantity of debris continued towards the ground in a northeasterly direction.

Cosmos 954 was placed in orbit in September 1977; it showed abnormal behaviour within weeks of its launching and its eventual re-entry was anticipated within the next few months. Actual date of re-entry was however uncertain, and it was not until early January, 1978 that this was foreseen to occur within the month. The American government notified all nations potentially affected on 19 January. On 20 January, the Canadian Department of National Defence (DND) warned all regional commanders and Nuclear Accident Support Teams (NAST) across Canada of the imminent re-entry, possibly over Canadian territory. On 23 January, several departments whose responsibilities might be touched upon by re-entry and landing were advised of the situation. Thus for many of those who became involved the advance notice was less than twenty-four hours; for some the information arrived after the event.

The known presence of a nuclear reactor on the satellite immediately raised concern about the nature of debris that survived to reach the earth's surface. The USSR had stated that Cosmos 954 was designed to burn up and disintegrate on re-entry, but in view of the telescopic and visual evidence of "landing" a search operation was at once instituted and as radioactive material began to be located a field program got underway that was to extend, with a pause during spring break-up, until mid-October, 1978.

Many problems were posed by the descent of Cosmos 954. There are towns along the south side of Great Slave Lake, but much of the area identified for search is uninhabited, and although this was an advantage in the sense that there were relatively small numbers of people endangered in that part of the area it was a disadvantage from the viewpoint of communications and access. Much of the search area lay in tundra and barrens, north of the treeline, and, under winter conditions, obvious landmarks such as rivers tend to be masked by snow and ice. Temperatures reach -40°C or lower, and with the wind chill factor perhaps as low as -100°C. Much of the area is utilized at one time or another of the year by native people and by other hunters and fishermen. Caribou herds migrate across part of the area. Two wildlife zones, the Thelon Game Sanctuary in the east and Wood Buffalo National Park in the southwest, were involved. Great Slave Lake supports an established commercial fishing industry and a flourishing sport hunting and fishing business. The defined search area traversed one of Canada's most promising uranium prospecting zones, so that in many spots the natural background radiation was relatively high, introducing confusion into the search.

All of these aspects meant that search had to be rapid in order to recover material of potential harm to people or to the environment and its wildlife population. With no detailed information on the type of satellite or reactor the only safe assumption to make, once radioactive debris had been located, was that it should be sought on the ground and removed as quickly as possible to a controlled holding area. A number of government agencies were quickly involved because of jurisdictional responsibilities or of special capabilities. Functional coordination of all these bodies was required, and was provided by assigning to DND the lead role in the search, and responsibility for the total logistics of the undertaking. The Atomic Energy Control Board (AECB) was given the responsibility for recovery, handling and disposition of debris located, that is, for matters related to the health and safety of people and the environment. This joint operation, commonly referred to as "Operation Morning Light" at the time, but in this report as Phase I, was maintained until spring break-up forced a hiatus in the search on 20 April, 1978.

Following the spring break-up period, the summer or

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Phase II operations were carried out under contract by James F. MacLaren Ltd. (1)* under the AECB lead, closing down in mid-October, 1978.

This report covers the two Phases, focusing chiefly on matters related to health and safety of people and the environment.

The search and recovery operations and the ensuing analytical work produced a great volume of photographic records and detailed chemical and metallurgical analyses. A report such as this cannot include all the data but will offer typical information enabling the reader to learn the variety of material found, the extent of the search, the hazards presented by the debris, the precautions taken to minimize these hazards and the obvious lessons learned (APPENDIX H). The full analytical and descriptive records of all finds are on file in the AECB offices, and it is expected that they will be available for examination by interested persons. This may be delayed until certain international legal questions concerning the re-entry and the ensuing search have been considered and satisfactorily resolved.

The report also presents summaries of work carried out by others, with references when possible to published records.

Appendices provide details and background information that will be of interest to a spectrum of readers.

2. The Search Area and Search Organization

The general area in which debris might be expected if it survived the fall was rather clearly defined as a result of NORAD's computer predictions of the re-entry. The original area identified extended from near Yellowknife on Great Slave Lake to Baker Lake, some 800 km to the northeast. This was divided arbitrarily into eight numbered search sectors (Figure 1). As the search proceeded, and with ballistic calculations incorporating size and mass data from recovered fragments, the search area became better defined. Nothing was found in sectors 5 to 8 inclusive, but sectors 9 to 14 were added on the west and southwest as material was discovered in that area. Figure 2 (at back of report) shows the location of the several classes of debris found and will be useful for reference in connection with Section 7.

The total sectored area of search in the NWT was about 124,000 square kilometers; additional search was carried out in selected parts of northern Alberta and Saskatchewan.

Under DND lead, the Canadian Forces Base at Namao, near Edmonton, became headquarters for the search, and Yellowknife became the forward base for search flights and for handling recovered debris brought back by recovery crews. The aircraft and other equipment called in for the operation have been described elsewhere (2) but in summary there were 13 Canadian aircraft in action at the peak of the search effort. These included C-130 Hercules, CC-138 Twin Otter, and CC-115 Buffalo propeller craft; and CH-135 Twin Huey, CH-136 Kiowa, and CH-147 Chinook helicopters.

Although most of the main searches were based in Yellowknife, at various times men and equipment were also based in Baker Lake; near Warden's Grove on the Thelon River; and at several of the communities on the south shore of Great Slave Lake. A location on Cape Dorset, Baffin Island (in line with the satellite trajectory) where it was suspected for a time that a part of the satellite had fallen, was also investigated over a ten-day period. These requirements naturally led to a division of equipment and expertise that made staffing and supply even more difficult.

With the short notice provided, the full Canadian effort required a few days to be established, but a scientist from the Geological Survey of Canada (GSC) in the Department of Energy, Mines & Resources (EMR), experienced in air-borne exploration for uranium, was on site on 24 January. A team from the AECB was already in Edmonton when the presence of radioactive debris was first confirmed. The capability of immediately undertaking the operation was greatly enhanced by the availability within a day of an American team experienced in search and recovery of radioactive material. The offer by President Carter of this expertise was accepted by Prime Minister Trudeau early on 24 January, and U.S. personnel (to an ultimate maximum of about 120) moved into Edmonton. These personnel included the Nuclear Emergency Search Team (NEST), organized several years previously by the U.S. Department of Energy, which had in effect been preparing for the re-entry of Cosmos 954 for several weeks. The following day the GSC gamma-ray spectrometer for use in air-borne searching was flown to Edmonton from Ottawa, and subsequently approximately 30 scientists and technicians from the AECB, GSC and Atomic Energy of Canada Ltd. (AECL) worked with the Canadian Forces and the U.S. NEST in the search and recovery operations. DND with flight crews, maintenance and support crews, NAST, and command staff, peaked at about 250. Thus the total manpower involved in the field reached several hundred, and in addition to them a significant number of staff from the concerned departments were involved in discussions on planning and coordination in Ottawa. An Interdepartmental Steering Committee met weekly in Ottawa during Phase I, under the chairmanship of a senior DND officer. Major field organizational responsibilities may be summarized as follows:

DND — On-scene command — responsible for overall operations.

*Numbers in parentheses refer to APPENDIX I, References

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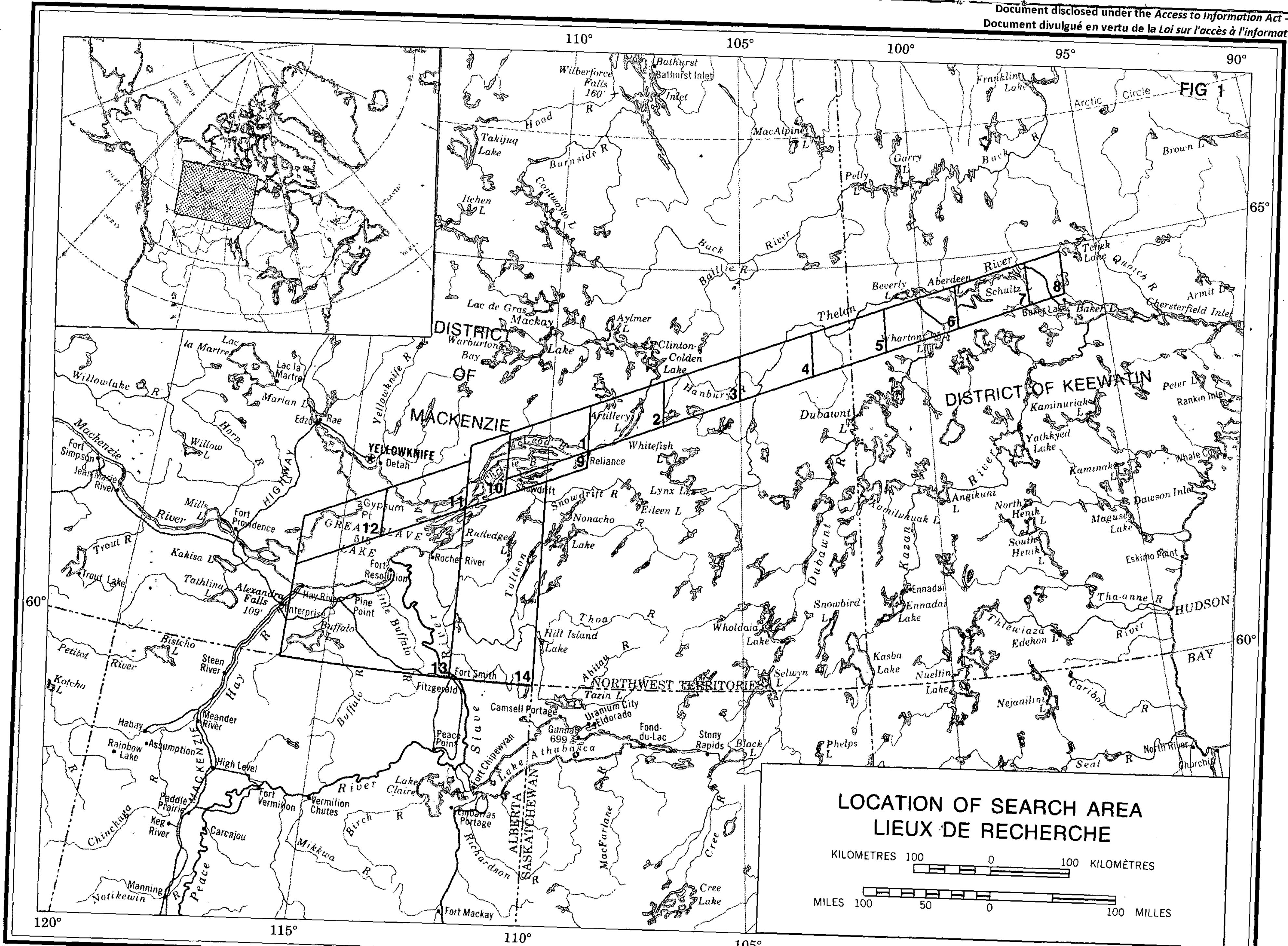

PRODUCED FOR THE ATOMIC ENERGY CONTROL BOARD BY THE SURVEYS AND MAPPING BRANCH, DEPARTMENT OF ENERGY, MINES AND RESOURCES, OTTAWA, CANADA.

ÉTABLIE POUR LA COMMISSION DE CONTRÔLE DE L'ÉNERGIE ATOMIQUE PAR LA DIRECTION DES LEVÉS ET DE LA CARTOGRAPHIE, MINISTÈRE DE L'ÉNERGIE, DES MINES ET DES RESSOURCES, OTTAWA, CANADA.

FIGURE 1 Location of area of fall, showing search sectors.

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AECB — Responsible for safe recovery, transportation and storage of debris.

EMR — Scientific management of the air-borne search under DND logistics command, using detection requirements established by AECB and other health physics groups.

For costs of the operations, DND assumed all expenses of the logistics — search flights, transport, man and material movements, establishment of access camps and fuel dumps — and AECB all expenses of its own, plus those of other federal departments (other than DND) that would become involved in matters of health, safety and the environment.

The successful completion of the Phase I operation reflects the immense effort by DND to meet both day to day exigencies and longer term plans. The fact that there were no accidents to people under search conditions underlines the thoroughness of the DND organization.

A brief chronology of the events from 24 January to 14 October, 1978 appears in APPENDIX A.

3. Roles of Other Federal Departments and Agencies

In addition to the effort of the GSC in supplying special equipment and expertise for the air-borne search and interpretation, other departments played a variety of roles. GSC staff have already published papers on the search techniques (3,4), and further reference to these will be made in this report.

AECL made major contributions to the program in several ways. All available shielded containers for radioactive material were provided for shipment of debris. Health physics and radiation monitoring staff were loaned to the AECB to augment its own limited resources. And most particularly, the Whiteshell Nuclear Research Establishment (WNRE) at Pinawa, Manitoba put its sophisticated analytical facilities at the disposal of the search and recovery operations. Eventually, essentially all samples recovered, large or small, were shipped to Pinawa for examination. This obviously interrupted ongoing programs, but WNRE proved a most willing helper in this work. This also provided a secure place for holding the satellite materials pending legal decisions on their ultimate disposition and for preventing radiation damage to the public or the environment. WNRE staff will be publishing detailed descriptions of debris (5); this present report will provide some examples of their work, but not full details. For much of the time during Phase I, a scientific representative from Defence Research Establishment, Ottawa, was also based at Pinawa to ensure proper liaison with the Edmonton base operations.

The Department of National Health and Welfare (NHW) contributed through the activities of the Radiation Protection Bureau (RPB). RPB already carries out air sampling at selected sites across Canada to measure radioactive fallout from nuclear test explosions; this was placed on a daily basis (for 24 days) after re-entry, and a new air sampling site was opened at Hay River during the search for Cosmos 954 debris. In addition RPB supplied a personal film dosimetry service for all involved Canadian personnel, and carried out laboratory studies under high priority to determine the hazards to people of minute radioactive particles that were found sprinkled over Great Slave Lake and the land to the south; RPB will be publishing a paper on the full results (6). Reference to this work will be made. RPB also monitored rain and snowfall, drinking water supplies in communities, and caribou meat from autumn hunting, for possible radioactive contamination. Personnel from the Department of Indian and Northern Affairs (INA) were involved because of their broad responsibilities north of 60° latitude, with respect both to the people and to the resources of the Territories.

Department of Fisheries and the Environment (DFE) staff considered aspects of environmental damage and undertook a program to monitor fish from Great Slave Lake for radioactivity.

An ice expert from National Research Council (NRC), Building Research Division, visited Cape Dorset to examine the reported occurrence that might have been related to the satellite but that was found to be a natural ice phenomenon (7).

The Ministry of the Solicitor General was involved because of the assistance available from the Royal Canadian Mounted Police (RCMP) in control of activities in the Territories, in communications, and in maintaining a supply of portable radiation-detecting instruments for travellers in the area. External Affairs (EA) was involved from the start as a result of the international implications of the event, and the intent ultimately to present a claim against the USSR for recovery of some or all of the large amounts of money spent on the search. Justice has advised on the legal requirements of "rules of evidence", under which all recovered material was handled, shipped and stored, and on the documentary requirements for the claim.

4. Acknowledgements

The search and recovery operations obviously depended upon the well-timed cooperation of a number of different federal agencies. In addition to a general acknowledgement of all the effort implied by the previous section, the AECB would like to recognize here specifically the cooperation of the Alberta Disaster Services, especially Mr. Ernie Tyler, the Alberta Dept. of Labour, particularly Mr. John Wetherill, Director of the Radiation Protection Branch, and the University of Alberta at Edmonton for analytical and data-processing assistance; the Saskatchewan Department of the Envi-

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TABLE 2

Fission and Activation Products in Cosmos 954 Debris and their Half-Lives[1]

(Chemical symbols given in parentheses)

Fission		Activation	
Isotope	**Half-Life**	**Isotope**	**Half-Life**
Strontium-89(Sr)	50.5 days	Chromium-51(Cr)	27.7 days
Strontium-90	29 years	Manganese-54(Mn)	312.5 days
Zirconium-95(Zr)[2]	64 days	Cobalt-58 (Co)	70.8 days
Niobium-95(Nb)[2]	35 days	Cobalt-60	5.27 years
Molybdenum-99(Mo)	66 hours	Iron-59(Fe)	44.6 days
Cesium-137(Cs)	30.17 years	Tantalum-182(Ta)	115 days
Barium-140(Ba)	12.8 days	Scandium-46(Sc)	83.8 days
Lanthanum-140(La)	40.2 hours	Antimony-124(Sb)	60.2 days
Cerium-141(Ce)	32.5 days	Plutonium-239(Pu)	24000 years
Cerium-144	284.4 days	Tritium	12.33 years
Ruthenium-103(Ru)[2]	39.4 days		
Ruthenium-106[2]	368 days		
Tellurium-132(Te)	78 hours		
Iodine-131(I)	8.04 days		
Neodymium-147(Nd)	11 days		

[1] The presence of residual uranium isotopes should also be recognized, though they play no significant role in this matter; uranium-235(U), 70 million years, and uranium-238, 4.5 billion years.
[2] Major fission products in Cosmos 954 debris.

5.4 Criticality

The neutrons produced by the fissioning of a uranium-235 nucleus have one of two essential fates; they may initiate additional fissions of other uranium-235 nuclei, or they may be lost (through absorption by non-fissile materials, or by escape from the system). With a large enough mass of fissile material, and/or with a configuration that curbs the loss of neutrons, the loss rate may be low enough to maintain a supply of neutrons for propagating the fission event, i.e. a chain reaction is produced. In such a state the assembly is referred to as "critical". Very high radiation fields would exist in the vicinity of such a "critical mass".

An immediate concern after the fall of Cosmos 954 was that a sufficiently large part of the core (if not all) might have survived re-entry and have achieved criticality, restarting the chain reaction. If, for instance, most of the core had landed intact and was able to melt enough ice and snow to become submerged in water, the mass might again have become critical. This is because the presence of water in effect cuts down the loss of neutrons. A mass of as little as 22 kg of highly enriched, undiluted uranium could become critical under these conditions. However, the results of the search quickly confirmed that the core had disintegrated so that criticality was no longer viewed as a likely hazard.

6. Air-Borne and Ground Searching

6.1 What To Look For?

A soon as the presence of debris on the ground had been confirmed, efforts were made to obtain from the USSR sufficient description of the satellite, and particularly of its power reactor, in order that the nature of potential hazards to people and the environment could be assessed. Without some guidance, search would be blind and perhaps misdirected.

The USSR quickly advised Canada that the reactor core contained uranium enriched in uranium-235, and later added that there had been a beryllium reflector. The core material was said by the USSR to be of non-explosive nature, formation of a critical mass being excluded. The reactor was also said to be designed so that on burn-up the active core would be dispersed into minute particles which would exclude the creation of radioactivity sources exceeding levels recommended by the International Commission on Radiological Protection. The USSR also stated that in their experts' opinions, the radiation levels resulting from any fallen material would be "practically" safe for people.

This information was useful in a general sense, but did not provide the total mass of material, nor the nature of the core, matters of prime concern when planning the extent of search and preparing for potential hazards that might be met. Some of the information arrived after the search operations had been in progress for some weeks. This meant that the sort of information desired had to be developed, as best as possible, as material was found and identified, and that certain assumptions were necessitated in regard to size of satellite and power of satellite. These assumptions will appear in the following sections of the report.

Although the USSR advice indicated that potential hazards were minor, the early finding of highly radioactive fragments dictated the necessity of a much more

(a) *External exposure of a significant part of the body*
Radiation exposure of a significant portion of the whole body could result from highly radioactive, large items. The magnitude of the dose would obviously depend upon the activity of the item, the distance from it, and the period of exposure at that distance. Smaller fragments would be unlikely to irradiate the whole body, but high exposure of parts of the body such as hands and feet would be possible upon close approach, or if a fragment were carried around in a pocket.

(b) *Contact or near-contact exposure of skin*
Such an exposure would result from picking up a radioactive fragment by hand, or by lodging of a particle in any part of the clothing. In such a case, the dose rate to the nearest parts of the body from even quite low activity sources could become significant. If exposure is prolonged over hours or days, the dose to the nearest tissue would be of concern.

(c) *Inhalation of small particles*
Tiny particles capable of entering nose or mouth might be inhaled, and if so would irradiate the lungs and perhaps other parts of the body.

(d) *Ingestion of small particles*
Ingestion might occur, for instance, during drinking or eating or by transfer from contaminated hands by cigarettes. If swallowed, radioactive particles would irradiate the gastrointestinal tract and perhaps other body organs.

These then were the considerations around which search criteria were required to be developed by health physicists. Their application is described in Section 6.2.

Instructions were issued to the population in the region to avoid and to report suspicious objects, in the light of the above hazards.

5.3 Reactor Aspects

During the operation of a nuclear reactor, a large number of radioactive isotopes (radionuclides) are produced by two different processes. When a neutron collides with and is absorbed by a fissile nucleus, such as that of uranium-235, the nucleus fissions (splits apart) into two lighter nuclei. The products of this splitting are referred to as *fission products*; some of these are stable isotopes but most are radioactive. When a neutron is absorbed by the nuclei of other, non-fissile materials in or around the reactor core as structural parts, these nuclei may become "activated", i.e. transformed into radioactive nuclei. The products of this second process are known as *activation products*.

Fission products from uranium-235 fuels commonly have atomic mass numbers centred around 90-95 and 135-140. The activation products encountered will depend on the composition of the materials close to the reactor core. In the case of Cosmos 954, stainless steel seems to have been used as structural material, and the most frequently encountered activation products have atomic mass numbers between 50 and 60 (that of iron is about 56).

The quantity of fission products formed in a nuclear reactor is proportional to the number of fissions that have occurred (and thus to the total energy generated).

The formation of activation products is also a function of the reactor power but is strongly dependent on the placement of the parent material relative to the reactor core as well.

The average rate at which the radioactive source, or radionuclide, decays is called the *activity* of the source. As more and more of the atoms disintegrate, there will be fewer left to disintegrate in the future, and the time required for half the atoms to disintegrate is called the *half-life*. Each radionuclide has its own half-life, but half-lives of different radionuclides range from fractions of a second to billions of years. Table 2 gives half-lives of the radionuclides encountered in Cosmos 954 debris.

As noted, radiation is emitted when an atom disintegrates spontaneously; usually, the radiation has a particular energy or group of energies. The distribution of these energies can be plotted to show the intensity at each energy; an example showing the energy distribution of the radiation from cesium-137 is given in Figure 3. Such a distribution is called the *energy spectrum* and is unique for a particular radionuclide so that the spectrum can be used to identify those radionuclides that are present — the spectrum is as distinctive as a finger print. This unique characteristic was used extensively in both the detection and the analysis of Cosmos 954 debris.

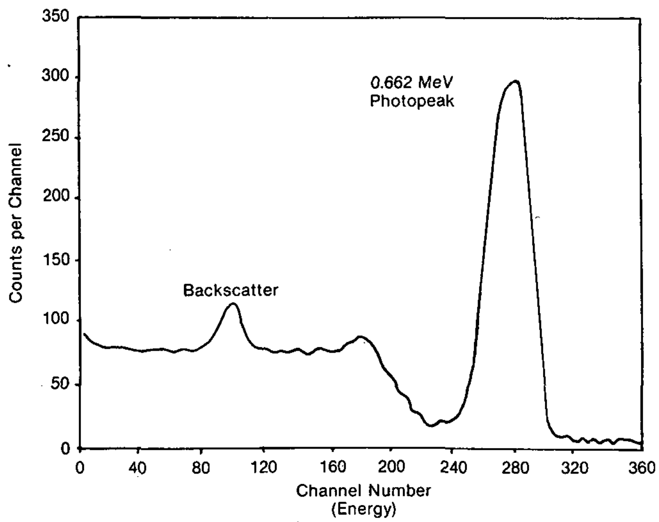

FIGURE 3 Sodium iodide energy spectrum for cesium-137

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Where possible, the area to be surveyed was traversed slowly in a grid pattern. While slowly walking these grids, the surveyor gently swung the radiation meter back and forth across his path. This had the effect of increasing the effective area of detection and reducing the shielding due to ground surface irregularities. The spacing of the grid lines depended on the potential use of the area, the expected strength of the sources, background radiation and the type of area being surveyed. In areas with strong sources and low background (8 μR/h), a spacing of 4 to 6 meters was considered to suffice. In areas with high background (20 μR/h) and low level sources, traverses as closely spaced as 1 meter were needed to ensure a reasonable level of particle detection.

In each community surveyed, grids were walked in all public and private areas with the exception of the roads and inhabited streets surveyed by a vehicle-mounted detection system. Attention was given to drip-lines, gutters, drains, snow fences, shrub-lines, snow dump sites and any other areas that appeared to have the potential for particle accumulation. Special attention was also paid to "sensitive" areas such as schoolyards, playgrounds and gardens as well as high traffic public areas, such as restaurants, municipal buildings, and food stores. Roofs of public buildings, hospitals and other areas with the potential for particle accumulation and exposure of large numbers of people were also surveyed. Lots that were uninhabited at the time of survey were searched if they had been cleared, or if their future use appeared likely.

In addition to coverage of communities and associated areas, a large number of other sites were investigated. These included cabins, hunting and fishing camps, lodges, mining and prospecting camps and fuel cache sites — in general terms, any area which might be frequented by man. A total of 130 remote sites were investigated. Based on data supplied by INA a list of sites for Phase II survey was prepared, and was supplemented with information from local government officials and RCMP, citizens' requests, and the consultant's inspection of the area. The area of required coverage was vast, extending over all of the territory south of Great Slave Lake and into northern Alberta and Saskatchewan. In addition, a number of sites situated on the islands in the east arm of the lake and on the north shore of McLeod Bay were investigated. A number of lodges and cabins south of the lake had been visited during the Phase I operations but repeat surveys were deemed necessary during the summer months to ensure complete coverage.

Ground vehicle surveys in Phase II were conducted with radiation detection equipment installed in vans, a procedure used on highways, roads and streets. On railroads, the detection equipment was mounted on a special track vehicle. Under winter conditions, ploughing of roads pushed snow and anything it contained to the passenger side of the route, and in the summer search instruments were mounted on this side of the vehicle. The vehicle could, of course, traverse in both directions, thus covering both sides of the road. The detectors were linked to an array of electronic equipment including a visual display which indicated the levels of radioactivity being measured. The detection equipment was initially calibrated with a standard cesium source and then checked in the field with "hits" found during the ground survey of Hay River.

Based on the field tests, a vehicle speed of 15 km/h was chosen as a satisfactory compromise between sensitivity of detection and speed of operation. The vehicle speed was later reduced to 8 km/h in the Fort Smith area and Wood Buffalo National Park as particle size and radiation strength decreased.

The principal instruments used for ground survey purposes are listed in APPENDIX C, according to the application, with the name or type of instrument and model number, brief information on the detector and range of readout, and the name of the manufacturer. Similar to the ground survey instruments, the principal component of the vehicle detection equipment consisted of sodium iodide scintillation crystals. However, whereas the hand-held instruments contained crystals of approximately 45 cm^3 volume, the vehicle crystal volume was approximately 13,600 cm^3. Furthermore, the vehicle system, like the air-borne system, was designed to discriminate between natural background radiation and radiation produced by Cosmos debris.

6.4 The Air-Borne Detection of Radioactive Debris*

It is a characteristic of fission products of a reactor that they emit gamma radiation with a higher proportion of low energy gamma-rays than those emitted by naturally occurring radioactive isotopes. Gamma rays from neutron activation of elements present in steel are also predominantly low in energy. Figures 4a and 4b compare a typical natural gamma-ray spectrum and a fission product spectrum, which illustrate this point. Table 3 shows the major gamma-rays emitted by fission and neutron activation products which are most likely to be observed soon after reactor shut-down. The half-lives of the various isotopes are also indicated.

Because of the high levels of radioactivity of rocks in the search area, mainly due to potassium-40 and decay products in the thorium series, a ratio technique was used to distinguish between natural and artificial sources of radiation. This ratio technique makes use of the fact that the radioactive satellite debris is dominated by low energy gamma-rays. The ratio of all gamma-rays

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thorough search than might have been suggested by that advice.

As will be brought out later, the USSR subsequently provided some confirmatory comments on the numbers of certain types of fragments, after they had been found. Otherwise the interpretative processes required for hazard estimation have rested on the assumptions referred to above.

6.2 Objectives and Criteria

The basic objective of the search was to minimize the radiation exposure of people living in the area in accordance with the principles of radiation protection in general, and with the "as low as reasonably achievable" ("ALARA") principle recommended by the International Commission on Radiological Protection (ICRP; see APPENDIX B). A second objective was to minimize the radiation exposure of wildlife and generally to protect against ecological damage.

In developing guidelines, it was necessary to take account of the following important factors:

(a) the need for very stringent standards in areas of human habitation;
(b) the need for somewhat less stringent standards in other areas while still ensuring a high degree of protection; this would include consideration of the probability of exposure and the possible duration of such exposures;
(c) the possible exposure pathways as outlined in Section 5.2;
(d) the detection capabilities of the search instrumentation;
(e) the existence of widespread natural uranium and thorium mineralization;
(f) the significant quantity of fission products estimated to be involved;
(g) the radioactive decay of the fragments which gradually reduces the activity levels, so that the radiological significance of any undetected fragments will be reduced with the passage of time;
(h) the requirement to search by use of fixed-wing aircraft or helicopters, and by ground surveys, either on foot or augmented by road vehicles where conditions were suitable.

At the time that guidelines were originally formulated, limited information was available on the detection thresholds for each type of survey. It was estimated that the detection threshold for fixed-wing aircraft surveys was such that fragments with a gamma exposure rate of about 10-50 R/h on contact, or 10-50 mR/h at 1 meter, could be detected; and for the helicopter surveys, the detection threshold could be improved to detect fragments with a gamma exposure rate of about 100 to 200 mR/h in close proximity or 0.1 to 0.2 mR/h at 1 meter. In practice, it was possible to detect fragments at lower levels in certain circumstances; thus, the almost negligible background radiation levels over frozen lake surfaces during winter permitted improved detection by helicopter surveys in those areas and the absence of snow during summer permitted lower level flights by fixed-wing aircraft, which could follow the variations in the terrain more easily than during winter when visual flying was more difficult due to the absence of recognizable features.

6.3 Search Procedures

The first coverage of the probable impact zone was carried out by C-130 Hercules aircraft bearing gamma-ray detection apparatus. These planes flew a pattern of lines spaced 1 nautical mile (1.85 km) apart at an altitude of 500 meters above ground level. One Canadian (GSC) and three U.S. gamma-ray spectrometers were employed. The first confirmed radioactive debris was detected by the Canadian instrument on the night of January 26/27 in Sector 1 (on the ice, 27 km north of Fort Reliance). This instrument contained a sodium iodide crystal of 50,350 cm^3 volume, and its operation and sensitivity have been discussed by Bristow (3).

Data were collected during flight on magnetic tape, which was subsequently analysed by computer to identify the nature of the radioactivity, and to distinguish between natural and man-made radiation. As material was located, this search procedure sufficed to show that radioactive material was likely to be found only in a strip about a few kilometers wide, roughly centred in the originally delineated zone but corrected southwards for wind drift. Within this redefined area, subsequent searching was done, with microwave ranging systems to enable pinpointing of locations, on a more closely spaced pattern with lines spaced at 500 m and a nominal height above ground of 250 m. Precise location was a necessity so that the site of a "hit" could later be visited, usually by helicopter, to enable the find to be recovered. Removal was always carried out under the eyes (and instruments) of experienced health physics or radiation monitoring staff.

It was a helicopter that first encountered radiation from the tiny particles (near Snowdrift). The advantages of being able to fly slowly and much lower than the Hercules were quickly recognized, and helicopters were employed for surveys at altitudes of 15 to 30 meters to:

(a) locate precisely any radioactive fragments detected by the fixed-wing aircraft surveys;
(b) survey the environs of human communities situated within the search area;
(c) survey roads and railways within the search area.

Ground (on foot) surveys were conducted in inhabited areas, including camp sites, using portable survey instruments capable of detecting radiation levels of 1 to 3 $\mu R/h$ above the natural radiation background.

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Where possible, the area to be surveyed was traversed slowly in a grid pattern. While slowly walking these grids, the surveyor gently swung the radiation meter back and forth across his path. This had the effect of increasing the effective area of detection and reducing the shielding due to ground surface irregularities. The spacing of the grid lines depended on the potential use of the area, the expected strength of the sources, background radiation and the type of area being surveyed. In areas with strong sources and low background (8 μR/h), a spacing of 4 to 6 meters was considered to suffice. In areas with high background (20 μR/h) and low level sources, traverses as closely spaced as 1 meter were needed to ensure a reasonable level of particle detection.

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TABLE 3

Some Gamma-Ray Emitting Isotopes Likely to be Observed Following Reactor Shut-Down

Isotope	Gamma-Ray Energy (keV)	Half-Life (days)	Origin
Zirconium-95	724,756	64	Fission
Niobium-95	765	35	Fission and decay product (daughter of zirconium-95)
Ruthenium-103	497	39.4	Fission
Cobalt-58	810	70.8	Activation of nickel-58
Manganese-54	835	312.5	Activation of iron-54

detected with energies between 300 and 1400 keV to those from 1400–2800 keV was found to remain relatively constant for all natural sources of radioactivity even while passing from water to land (Figure 5a). The radioactivity over water arises from cosmic radiation, the radioactivity of the air, the aircraft and its equipment (radium dials, etc.). Radioactive satellite debris is indicated by a significant increase in the low/high energy ratio (Figure 5b). Additional confirmation is provided by the increase in total radioactivity.

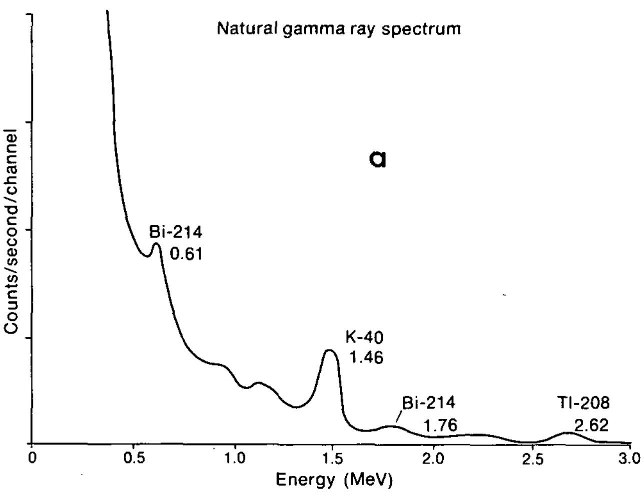
Bristow (3) describes in more detail the procedures that were used to detect the radioactive satellite debris.

7. Description of Recovered Debris

7.1 General

Table 4 summarizes the nature of material found in the search. Simply by analogy with other earth-orbiting satellites, Cosmos 954 has generally been assumed to have weighed in the order of 4 or 5 tons; the amount of material recovered (about 65 kg) is not only a small fraction of the whole but obviously represents for the most part a few special parts of the satellite. Most of the general structural components, presumably of steel, have not been found, and it is surmised that these components have oxidized to a finely-divided powder, or "burned up", during re-entry. On the other hand certain beryllium cylinders have suffered little if at all during re-entry.

Individual identification of each recovered fragment is given in APPENDIX D, Summary of Fragments Re-



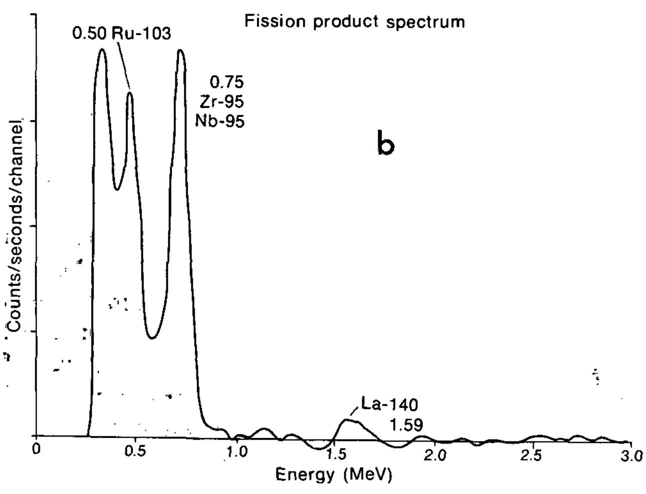
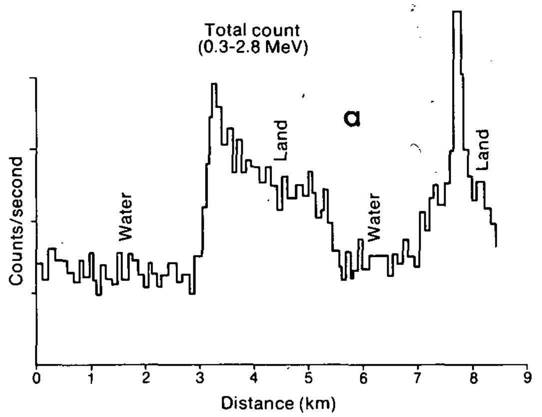


FIGURE 4 Typical natural (a) and fission (b) product gamma-ray spectra.



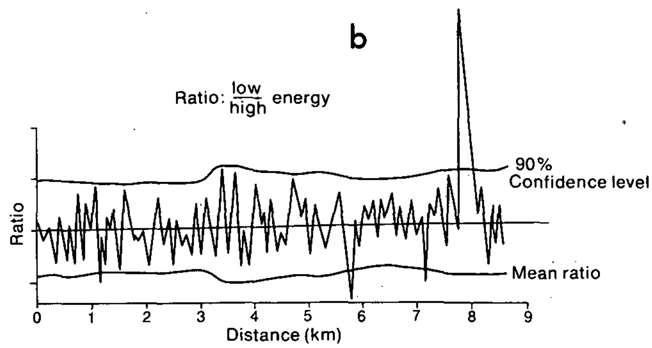


FIGURE 5 Example of procedure used to detect radioactive satellite debris (the high peak in each case).

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covered; this gives sample identity as a "Hit Number"*, the location, the in-situ radiation field, and some physical description. This is the "Hit List", with spurious records and natural occurrences deleted.

Figure 2 (map at back) indicates the locations and pattern of distribution of fragments.

In spite of the relatively small amount of material recovered, its safe disposition for shipping purposes put a great strain on available lead-lined containers. A description of container types and of the careful procedure followed in moving debris from Edmonton to WNRE at Pinawa is given in APPENDIX E.

The recovered material divides itself into two rather distinct classes, as suggested in Table 4, and they will be treated separately in sections 7.2 and 7.3.

In the following sections of the report, examples of both types of debris are described with particular reference to the information provided by WNRE. At WNRE each item was put through part or all of a complex analytical examination scheme. It was monitored for radioactivity, photographed and given a brief description. Simple tests were done to determine its character, for example density, magnetic susceptibility, and electrical conductivity. Where appropriate, samples were taken for further analysis and radiochemical measurements. Because of radioactivity, many of these operations had to be done inside a shielding "hot-cell" equipped with remote manipulators and a leaded-glass window.

Samples taken for further study were analyzed by

TABLE 4

Summary Description of Debris Recovered

Material	Size, Weight	Radiation Level When Found	Sector
Large Fragments			
4 steel plate fragments	largest 225 mm x 75 mm x 6.5 mm weighing 272 g.	To 200 R/h on contact	1, 11, 12
41 beryllium rods (some with niobium sheaths)	100 mm x 20 mm diam. About 51g each	600mR/h to 100R/h on contact; 30 to 150mR/h at 1 meter	1(17 rods), 2(21 rods), 10(3 rods).
6 beryllium cylinders	250 mm x 100 mm diam. 3.6 kg. each	5 to 15R/h on contact. 40 to 800 mR/h at 1 meter	2(5 cyl.) and 3(1)
Tubes, rods, plate (the "antlers")	6 rods about 1 meter long attached to plate. 20 kg. total	To 15R/h on contact. Variable over the debris	4 (near Warden's Grove on Thelon River)
Steel tube (the "stovepipe")	About 500 mm long, 360 mm diam., 2.5 mm wall. 18.2 kg.	Non-radioactive	1 (near Ft. Reliance)
Other Chunks, Flakes, Slivers	Variable	Most 10 to 30 R/h on contact; one to 500R/h	Chiefly 10
Small Particles			
About 4000 recovered	a) spherical, 1mm to less than 0.1 mm diam. Mass 5 mg to less than 100 μg b) irregular, or flaky. Some several mm on a side and very thin and friable	most in the range 10 to 100 mR/h at 1 meter	10,11,12,13,14

The first class — the larger objects — were found in a narrow zone stretching from roughly the centre of Great Slave Lake to Artillery Lake; an isolated object was found on the Thelon River near Warden's Grove. This is a total distance of well over 500 km.

The second class comprises smaller particles whose landing was affected by the wind currents in action at the time. They were thus carried far to the south of the landing path over an area of 100,000 square km or more.

gamma spectrometry for radionuclides present, by X-ray and emission spectrography for their elemental composition, by electron microscopy and X-ray diffraction for structure and morphology, by mass spectrometry for nuclear fuel content and by chemical and other instrumental analysis for a variety of other information.

The result was that a great deal became known about the character, identity, and potential hazard of the variety of items that survived re-entry. Identification of alloys used in the satellite was possible (and in some instances even the method of fabrication became apparent). The solubility in hot and cold water and likely behaviour of radionuclides in nature was also investigated.

* The identification code, often used as a sample number, indicates "Morning Light" (ML), and the sequential position of the item in the series of fragments recorded in a sector, e.g. 1(1) is the first item in sector 1, 7(3) is the seventh item in sector 3, and so on.

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The first shipment arrived at WNRE on 5 February, 1978; 15 major shipments in all were received. More than 4700 analyses were reported, and more than 40 scientists and support staff were involved at one time or another. A measure of the total is provided by the number of man-hours recorded for analysis and operations such as handling and storage; the figure exceeds 9000.

WNRE's final storage actions completed the sequence of careful identification and control of samples from their first discovery to their ultimate disposition in storage facilities. This provided the final entry on the travelling form shown in Figure 31, APPENDIX E.

7.2 Large Fragments

7.2.1 Location

Fragments were found in a well-defined band as shown in Figure 2. Generally the size and weight of fragments increased towards the east end of the trajectory, consistent with ballistics considerations.

Most of the small beryllium rods were clustered over a distance of 75 km. The beryllium cylinders also occurred as a group over about 60 km. The fragment referred to as the "antlers" was the largest fragment recovered and the furthest east on the track. The four recovered steel plate fragments were widely scattered (over 300 km); one (in sector 12) was the most westerly object found.

The miscellaneous smaller pieces, mostly from Sector 10, vary greatly in shape and size.

The fragment known as the "stovepipe", the only non-radioactive debris located, was spotted by eye by chance in Sector 1 during a flight to another location.

7.2.2 Description of Selected Fragments

Typical fragments of each type are described in detail in the following sections along with results of analyses performed on them. For space-saving purposes, use is made of the chemical symbols for elements, as listed in Table 2. It should be noted that radiation readings are meter readings, not corrected for background.

Steel Plate Fragments

The largest steel plate, ML-1(1), is an oblong fragment, about 225 mm by 75 mm by 6.5 mm thick, weighing 272 g and with a density of 5.3 grams per cubic centimetre (see Figures 6 and 7). The object has a convex-concave surface on which a slag-like material had been deposited. It appears to be part of a large cylinder with the axis of the cylinder parallel to the longest dimension of the plate. The presence of the slag layer and the appearance of the edges of the plate indicate that extensive melting and resolidification has occurred. It was determined by emission spectroscopy that the main plate material is an austenitic stainless steel similar to American Iron and Steel Institute Type 321. An analysis of the slag-like material showed that it is an oxidized form of the same material.

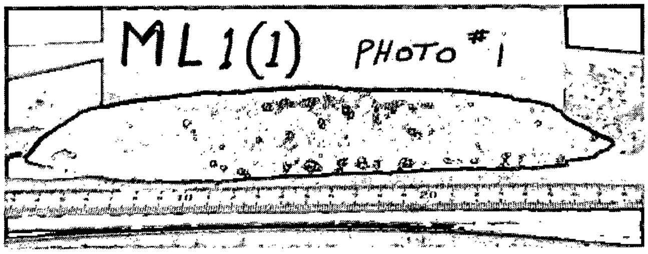

FIGURE 6 Convex side of steel plate fragment ML-1(1).

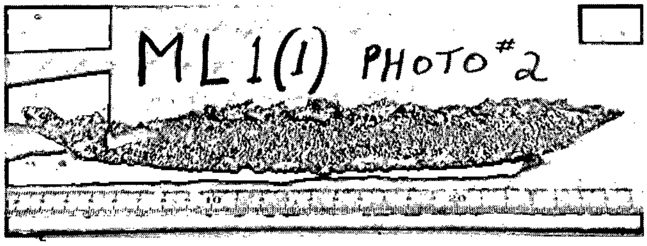

FIGURE 7 Concave side of steel plate fragment ML-1(1).

A few small granules of uranium-rich material were also embedded in the slag layer. These were later shown to be similar to recovered fuel particles.

The in-situ radiation field of ML-1(1) was measured as high as 200R/h near contact. However, the radiation field was not uniformly distributed over the convex and concave sides; at near contact it was found to vary from 1 R/h to 200 R/h of beta/gamma radiation over distances as short as 5 mm.

Gamma spectrometry measurements showed that the major activity from the main plate material came from activation products, while fission products and activation products in about equal amounts contributed to the activity of the slag-like material. Quantitative activity measurements were made on samples taken from different areas of the plate: on a piece of main plate material dissolved in an appropriate solution, on a piece of slag material similarly dissolved, and on loose granules which were easily detached from the main plate (Table 5).

The activation products are those expected with stainless steel. Other radionuclides are typical fission products in irradiated fuel and were mostly located between the main plate metal and the slag-like coating. This area was found (by beta/gamma autoradiography) to possess especially high activity.

Another plate-like fragment (ML-1(12)) is shown in Figure 8. This object was found further west than any other. It is also stainless steel but does not exhibit the same degree of overheating as ML-1(1).

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TABLE 5

Quantitative Activity Measurements on Portions of Steel Plate ML-1(1)

(Activities in millicuries per gram)

Portion	Plate Metal Dissolved	Slag Dissolved	Loose Granules
Date Counted:	13 Feb. 1978	13 Feb. 1978	15 Feb. 1978
Activation Products			
Cr-51	2.3	1.5	1.52
Mn-54	1.4	0.3	0.54
Co-58	8.4	2.7	N.D.*
Co-60	0.02	0.04	N.D.
Fe-59	0.09	0.08	N.D.
Fission Products			
Zr-95	0.11	0.54	1.4
Nb-95	0.54	0.57	1.3
Ru-103	0.65	0.32	1.3
Ba-140	0.51	1.5	N.D.
Ba/La-140	N.D.	N.D.	4.9
Ce-141	0.06	0.78	1.2
Mo-99	0.01	N.D.	N.D.

*N.D. = not detected.

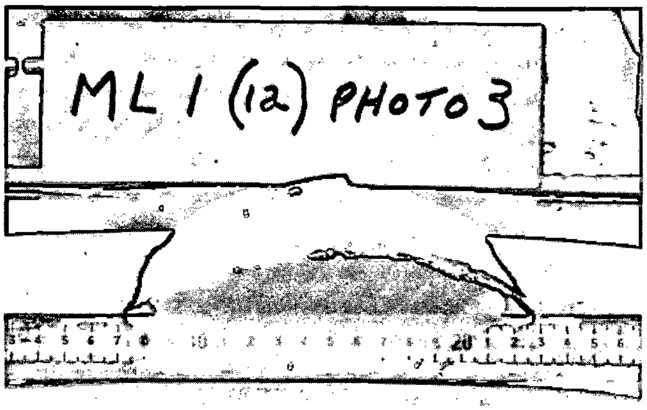

FIGURE 8 Steel plate fragment ML-1(12) showing surfaces less damaged by re-entry.

Judging by the level of activation product activity, the four plate fragments that were found originated near the periphery of the reactor core.

Beryllium Rods

As previously mentioned, the largest group of similar fragments recovered comprises 41 beryllium rods which all fell in their own portion of the "footprint" of the satellite (see Figure 2). These were apparently all about 100 mm long and 24 mm in diameter, and weighing about 50-55 g with a density of about 1.8-1.9 g/cm^3. Rods appear to have been separate, individual slugs and not the result of break-up of longer bars.

Surfaces were commonly scorched, with evidence of some material having become molten and then resolidifying. Some were noticeably shortened and rounded, indicating ablation. Remnants of a shiny corrugated cladding were observed on many rods, and some pieces of cladding were also recovered separately. Figure 9 shows a partly burnt rod still in its cladding.

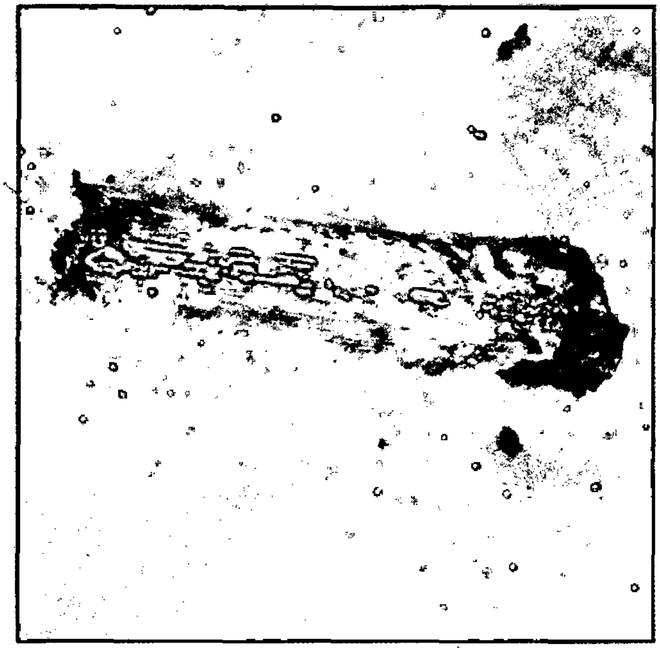

FIGURE 9 One of 41 beryllium rods, still with a niobium cladding, as it was found lying on the snow on 7 February, 1978.

A metallographic transverse cross-section of one rod showed that it was solid throughout. The major impurities were iron, tin and zinc, with total impurities being less than 1% by weight. A similar analysis on an example of the cladding (ML-12(1)) showed it to consist largely of niobium metal with beryllium and lesser calcium and iron as major impurities.

In the body of the rods, activity was found mainly to be due to activation products, with Cr-51 and Sc-46 being most intense, and a small amount of fission products. Surfaces showed mixed activation and fission products. Quantitative gamma spectra counted around 15 February 1978 from three samples taken from two different rods gave the following results (Table 6).

Except for Ta-182, an activation product of naturally-occurring Tantalum-181 and often associated with niobium, all activation products relate to the impurities detected in the beryllium of the rods. The fission products and Ta-182 are probably contamination from remnants of the cladding still adhering to the Be rods.

Two pieces of cladding were analysed: ML-12(1) and a piece detached from ML-11(1). The quantitative analysis of ML-12(1) gave the following results (as of 20 February 1978) (Table 7).

The major gamma activity is due to Ta-182. Most of the remaining activity is from fission products deposited on the surface of the cladding.

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TABLE 6

Radionuclides in Beryllium Rods

(Activities in microcuries per gram)

Sample	Sc-46	Cr-51	Mn-54	Fe-59	Co-58	Co-60	Te-132	La-140	Ta-182
ML-5(1) (metal)	2.1	7.7	0.4	0.3	0.4	0.2	0.001	0.03	0.08
ML-11(1) (metal)	1.0	3.8	0.4	0.2	0.5	0.2	ND*	present*	present
ML-11(1) (Surface plus metal)	10.0	4.3	1.0	0.1	0.05	0.2	ND	ND	present

*ND = not detected; "present" = detected but too low to measure

TABLE 7

Radionuclides in Niobium Cladding ML-12(1)

(Activities in microcuries per gram)

Mn-54	Zr-95	Nb-95	Ru-103	Te-132	I-131	Ba/La-140	Ce-141	Ta-182
5.4	27	73	46	43	24	27	Present	81

TABLE 8

Radionuclides in Melted Snow Recovered With Beryllium Rods

(Activities in millicuries per litre)

Sample	I-131	Cs-137	Ba/La-140	Ru-103	Ce-141	Zr-95
ML-6(1)	2.7	0.57	3.5	0.03	N.D.	N.D.
ML-24(1)	0.02	0.01	0.35	N.D.	0.003	N.D.
ML-6(2)	0.07	0.003	0.09	N.D.	0.01	N.D.
ML-7(2)	0.46	0.78	5.1	N.D.	0.02	N.D.
ML-8(2)	0.35	0.05	0.57	N.D.	0.03	0.03

Major gamma activity on the piece from ML-11(1) was from Ta-182 but Co-58 was also present; among the fission products detected Ru-103 was most intense and at lower levels were Ba/La-140 and Ce-141.

During Phase I, it was commonly the case that snow and ice adhered to recovered debris, and were enclosed in the container used for transport. In several instances the resulting water was analysed to estimate contamination around debris. With respect to beryllium rods the accompanying water was found to carry mostly fission products, some of them of the volatile type. Table 8 illustrates the nature of such contamination (counting date 20 February, 1978).

The role of these beryllium rods in the reactor is not known. However, they were possibly part of the reflector which the USSR stated had existed.

Beryllium Cylinders

Six large and apparently identical beryllium cylinders were recovered, from a cluster of sites. They are about 100 mm in diameter and 250 mm long, and weigh about 3.5 kg. Each end has six short identations equally spaced around the circumference and the indentations on opposite ends are lined up. In addition, one end has a circumferential groove (Figure 10).

A chip taken from one edge showed the material to be beryllium, with about 100 ppm of aluminum as the major impurity. Both longitudinal and transverse sections were cut from one cylinder, confirming that they were solid (the tapered end on some had suggested a capping)*. Emission spectroscopy results on sections also confirmed that they were homogeneous in composition.

Gamma spectra recorded for surfaces of three of the cylinders showed the activity to consist of mixed activation and fission products where the surface was dirty, but only activation products from clean surfaces. Some of the fission products detected were Zr/Nb-95, Ba/La-140, Ce-141 and Cs-134, but their activity level was always lower than that from the activation products, mainly Ta-182, Sc-46, Co-60, Co-58, Mn-54 and Fe-59.

* This procedure also confirmed that unless such operations are carried out under the most stringent control, contamination by beryllium dust results, and may become rather wide-spread before it is recognized. The clean-up procedure once the dust has spread is a major undertaking.

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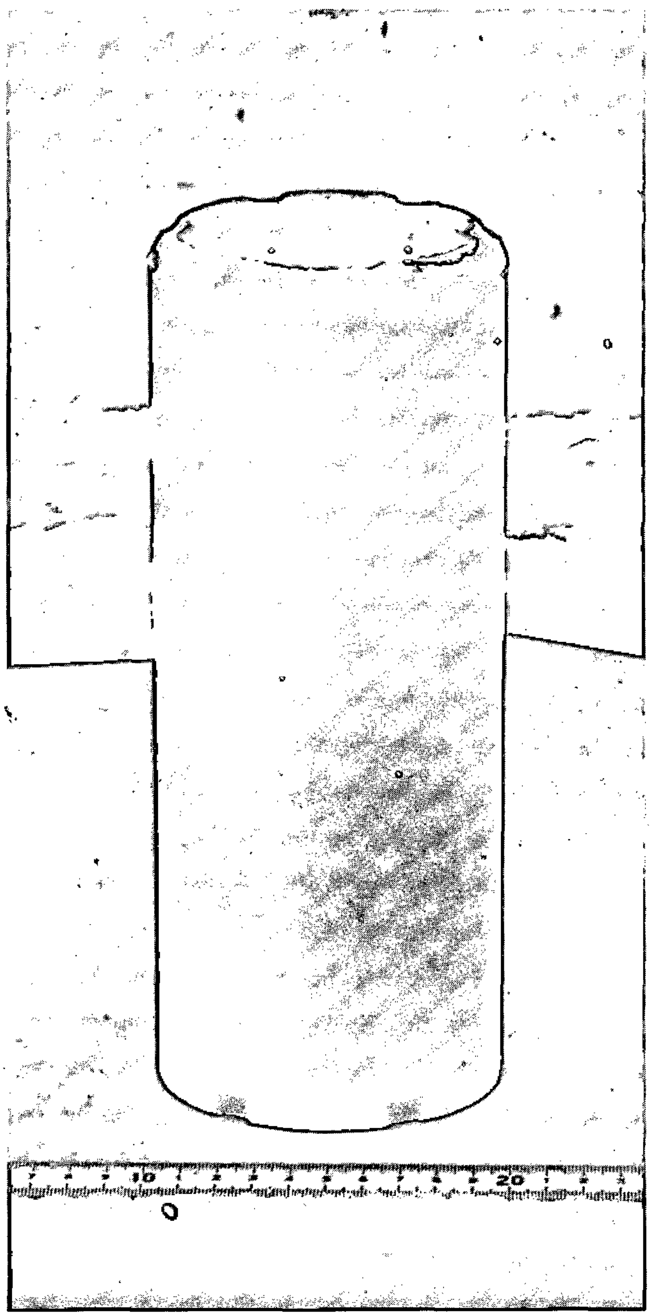

FIGURE 10 One of six beryllium cylinders, ML-29(2). Note the generally unaltered appearance of the surface.

The exact role of these large beryllium cylinders in Cosmos 954 is unknown, although again they were possibly associated with the reflector. The excellent condition in which the cylinders were recovered contrasts with the extensive damage received by the smaller rods and suggests that they were more protected during re-entry.

"Antlers"

The largest satellite fragment (actually in two pieces) found was the complex structure shown in Figures 11 and 12 and nicknamed the "antlers". This was the material fortuitously discovered by two of a group of six men wintering on the Thelon River.

The structure consists of six legs or tubes, three still attached to a circular base plate and three others which apparently broke loose on impact. When attached, the 700 mm legs were held about 125 mm apart by four rows of cross-braces. Much of the exterior surface was covered by a white powder which was determined by powder X-ray diffraction to be hydrated lithium hydroxide, $LiOH.H_20$. Darker deposits on the antlers were analysed as lithium hydride, LiH. The cross-braces were found to contain both LiH and $LiOH.H_20$. Samples from the base plate and from the legs were analyzed by emission spectroscopy and found to be made of stainless steel with a composition similar to that of other fragments.

To ensure that the legs of the "antlers" did not contain hazardous materials, and, if possible, to aid in definition of the "source term", legs were cut open. Cross-sections (Figure 13) revealed that each leg (about 33 mm. diameter) carried an inner tube (about 25 mm diameter), the annulus between being filled with a black powder (either boron silicon carbide or boron carbide, or both). The inner tube in turn held a jointed arm that was independently movable, and of which tubular sections held either the black powder or lithium hydride.

The size of the "crater" associated with the "antlers" and its distance down the trajectory were both anomalous. However, both may be explained by the large amounts of lithium hydroxide found. It has been calculated that the assemblage could have contained as much as 50 kg of lithium hydride which would have reacted, after impact, with melted ice in a very vigorous (exothermic) chemical reaction, spattering the products over a large area and producing the "crater"*. Furthermore, the distance that the "antlers" travelled down the trajectory is a result of the extra mass of lithium hydroxide present while in flight.

The complex structure of the whole assembly seems consistent with a reactor control function. The boron-rich link on the movable rods suggests that these were reactor control or shut-off rods. The large amount of lithium hydride would have provided a neutron shield for the satellite's electronic components.

* When the "antlers" were first found, their nature and the size of the "crater" suggested the possibility that part or all of the reactor core might be present as well, under the ice. A neutron-detecting device on an extension cable was therefore flown to the site and inserted through holes drilled through the ice. It was discovered that the river was relatively shallow in that spot, and a thorough search failed to locate any foreign material or radiation. Subsequently, as will be explained in a succeeding section, the discovery of the small particles of fuel showed that the core had disintegrated far to the west and at some elevation above land.

DFE Water Survey personnel sampled the river water above and below the "crater", and analysis by the University of Alberta laboratory in Edmonton failed to show the presence of radionuclides. With removal of the "antlers" and all possible smaller debris in the area, the potential for contamination of the water was largely eliminated.

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FIGURE 11 The "antlers" as discovered in ice and snow on the Thelon River; photographed 29 January 1978.

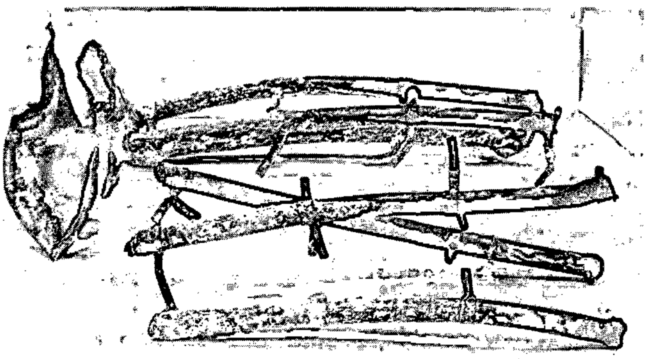

FIGURE 12 The "antlers" photographed at Whiteshell Nuclear Research Establishment. The white coating is hydrated lithium hydroxide.

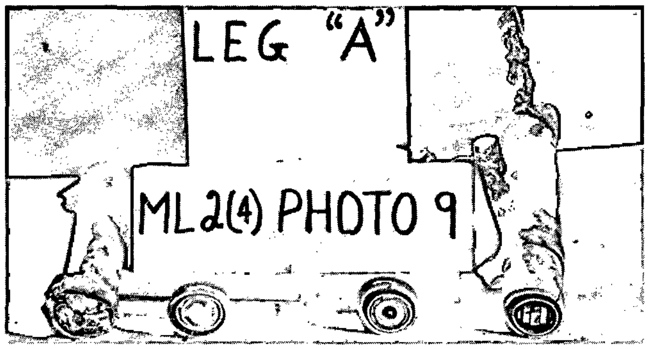

FIGURE 13 Cross-sections of one of the legs of the "antlers", resulting from studies to ensure that they did not contain unexpected hazardous materials.

"Stovepipe"

The "stovepipe" is shown, as found, in Figure 14. It is simply a large empty pipe about 500 mm long (varies from 420 to 510 mm due to uneven erosion during re-entry) by 360 mm diameter with a wall thickness of 2 to 3 millimetres. One end is jagged and shows evidence of extensive melting, the other end is terminated by a machined flange or rim. The rim also appears to have been partially melted during re-entry, and then resolidified. Other fragmented and charred debris was recovered nearby and when reconstructed (Figure 15 page 18) appeared to form a fibrous seal over the rimmed end.

Apart from the non-metallic (probably thermosetting plastic) material assumed to have capped the flanged end of the pipe, the metal is apparently a mild steel; one area exhibited a fully developed martensitic structure. A factory marking on the pipe is shown in Figure 16, page 18, with one apparently Cyrillic letter (ya) shown.

This fragment was not radioactive and must therefore have belonged to a part of the satellite not closely associated with the reactor. Because it presents no hazard to people this fragment was placed on exhibition in the National Museum of Science and Technology in Ottawa, Ontario, in October 1978.

Other Chunks, Flakes, Slivers

One curious fragment nicknamed the "moose hoof", is shown in Figure 17 page 19. It is basically a truncated solid cylinder of about 100 mm in diameter and 60 mm along its maximum length, bisected by a 45° plane. It is cut by a groove about 20 mm wide and about 50 mm deep. It was heavily covered with a black flaky deposit.

Emission spectroscopy results on the metal indicated only the presence of beryllium (consistent with a density measurement).

Gamma radiation was 6 R/h, near contact. Two portions were subjected to gamma spectroscopy. The first sample consisted of a piece of the black flaky deposit, in which activity was mainly due to the usual activation

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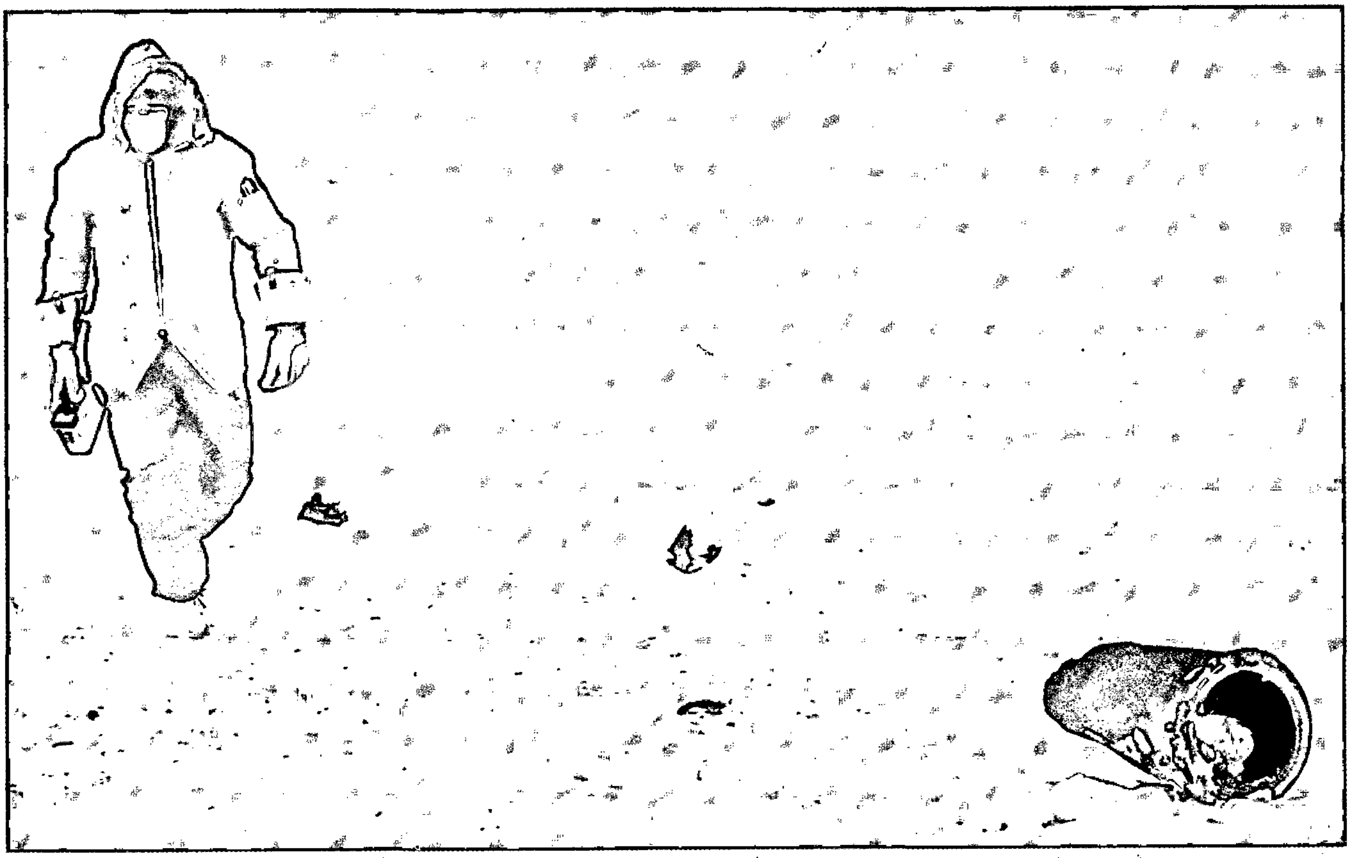

FIGURE 14 The "stovepipe" surrounded by smaller and more fragile debris on the frozen surface of Great Slave Lake.

products of steel, and to fission products (Ce-141, Ru-103, Ru-106, La-140, and Zr/Nb-95) at lower levels. In the second sample, of clean metal, the activity was mainly due to fission products, Ce-141, Ru-103, Zr/Nb-95, Ba/La-140, Ce-144, and some steel activation products at lower levels.

Other fragments were generally very small and of irregular shape. Judging from the radiation fields measured and the type of fission products detected they must have been in or near the reactor core. One such fragment (ML-3(10)) is shown in Figure 18 page 19. This presented the highest activity of any such fragment recovered: a gamma field of 500 R/h near contact was measured. A detached flake was quantitatively analysed by gamma spectroscopy with the following results (as of March 1, 1978).

TABLE 9

Radionuclides Accompanying Flake From ML-3(10)

(Activities in microcuries per gram)

Co-58	0.3
Zr-95	30.
Nb-95	11.6
Ru-103	11.4
Ba/La-140	5.4
Ce-141	300.
Nd-147	54.

Except for Co-58, all are typical fission products. In another portion of the same sample analysis showed the presence of uranium as well. The internal structure of this fragment suggested that two or more components (including uranium fuel and steel) had been mixed by fusion.

7.3 Small Particles

7.3.1 Location

A large number of very small particles, quickly determined to represent the fuel of the reactor (presumably as foreseen by the USSR), were recovered during both the winter and summertime searches. A single particle is shown lying in snow, in relation to a Canadian 1-cent piece, in Figure 19. Particles were recovered primarily from NWT communities south of Great Slave Lake, but significant numbers were also recovered from roads, railways, cabins, lodges, etc. in the affected zone*; from areas sampled on the surface of Great Slave Lake and other lakes (before break-up); and to a much lesser degree from communities in Northern Alberta and from

* During Phase I, 42 cabins and lodges were visited by helicopter; at six of these, particles were found (nine in all); during Phase II, 130 remote sites (including many of those done under winter conditions) were visited, producing 50 particles.

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FIGURE 15 Reconstruction of one end of the "stovepipe" from debris found on the snow nearby. Note the visual evidence of melting of the rim.

FIGURE 16 Factory marking on "stovepipe"

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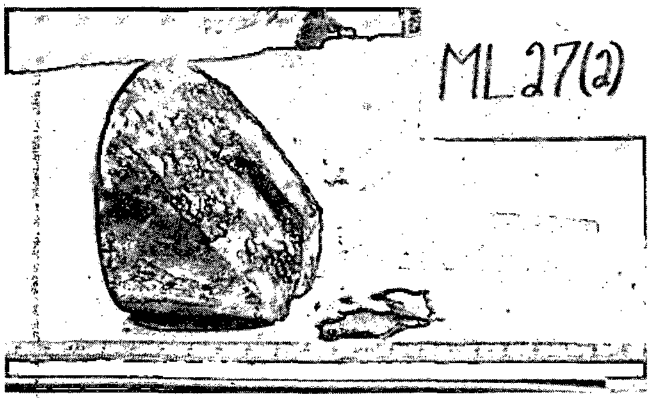

FIGURE 17 The "moose hoof", a beryllium fragment (ML-27(2)).

uranium prospecting sites in northern Alberta and Saskatchewan. These finds, along with the results of airborne gamma surveys, have indicated an extensive area over which such particles were spread (Figure 2).

The area affected by particles is in excess of 100,000 square kilometers. It is known with only some accuracy. On the western side, none were found west of Hay River, and the western part of Buffalo Lake was apparently not affected (according to the winter ice-surface survey). This defines the western side of the area rather clearly.

Snowdrift represents the eastern limit on Great Slave Lake. South of Snowdrift there are no roads for access; there are numerous lakes and rivers, and on these many cabins and lodges for hunting and fishing purposes. During both winter and summer periods, many of these were visited by helicopter and the grounds searched for debris. The map prepared by James F. MacLaren Ltd. (1) under the Phase II contract is reproduced as Figure 20, and shows particles found at sites visited between Great Slave Lake and the 60° parallel.

The southerly extension is less clear. There were sections of roads, both north and south of Fort Smith, that produced no particles while adjacent sections yielded particles. Thus the fall was not evenly distributed everywhere. No particles were found in Fond-du-Lac or Camsell Portage in Saskatchewan, although prospectors reported their occurrence west of Camsell Portage on the northwest side of Lake Athabasca (Spring Point). None were found in Embarras Portage in Alberta, but a few were located in Fort Chipewyan and as far south as latitude 58° on either side of the Saskatchewan-Alberta border.

Thus it appears that although particles were clearly carried to the south and southeast the distribution was not even. Although adjacent to Great Slave Lake all towns and roads in the zone exhibited particles, there is evidence from road surveys in which stretches with few or no particles were encountered that the fallout "fingers out" to the south. Furthermore, with distance from

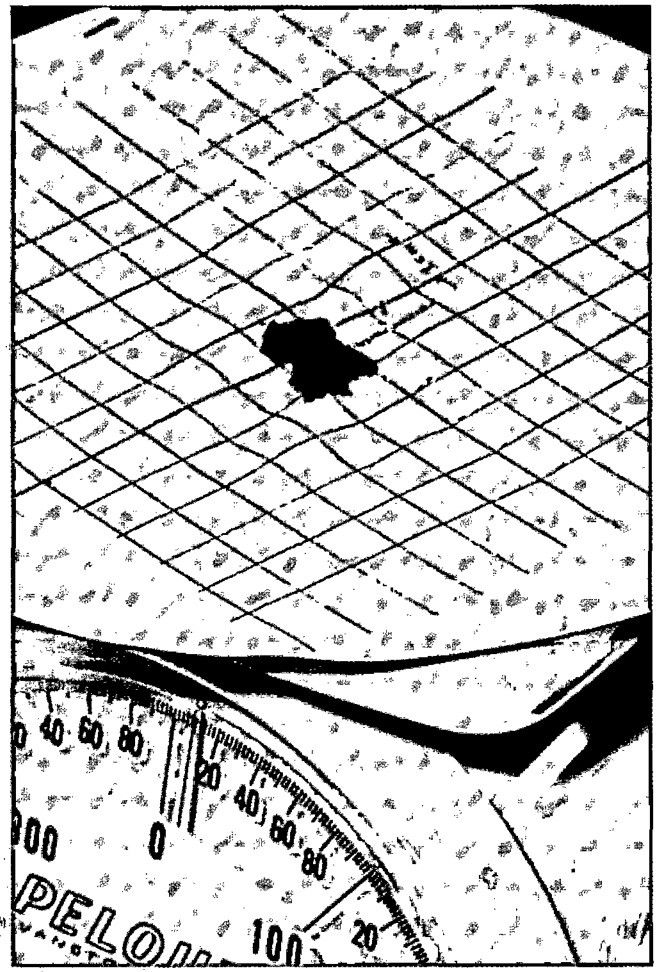

FIGURE 18 The "hottest" fragment discovered, presenting a gamma radiation field of 500 R/h near contact. The possible presence of such fragments strengthened the thoroughness of the search because of their potential hazard to life.

the presumed source over Great Slave Lake, the size of particles decreased (small particles were carried farther) so that in effect their distribution may be said also to "fade out" as they become too small to detect.

The southwest limit of the particle area is poorly known; there was no ready means for searchers to penetrate this section. The search was therefore carried no further in this direction on the basis that a) particle fall was spotty on the road north of Peace Point; b) Embarras Portage was clear of material detectable by the regular search techniques; c) Fort Chipewyan yielded few particles and they were small; and their detection required very close instrument search; d) no populated places were identified in the indicated area.

The delineation of the particle area in Figure 2 is intended to indicate that there is this general uncertainty about the southern extension. It may be that actually there are one or more tongues of fall-out, perhaps a main one, extending over Fort Chipewyan and the west side of Lake Athabasca to the Richardson River, where a few particles were found by prospectors.

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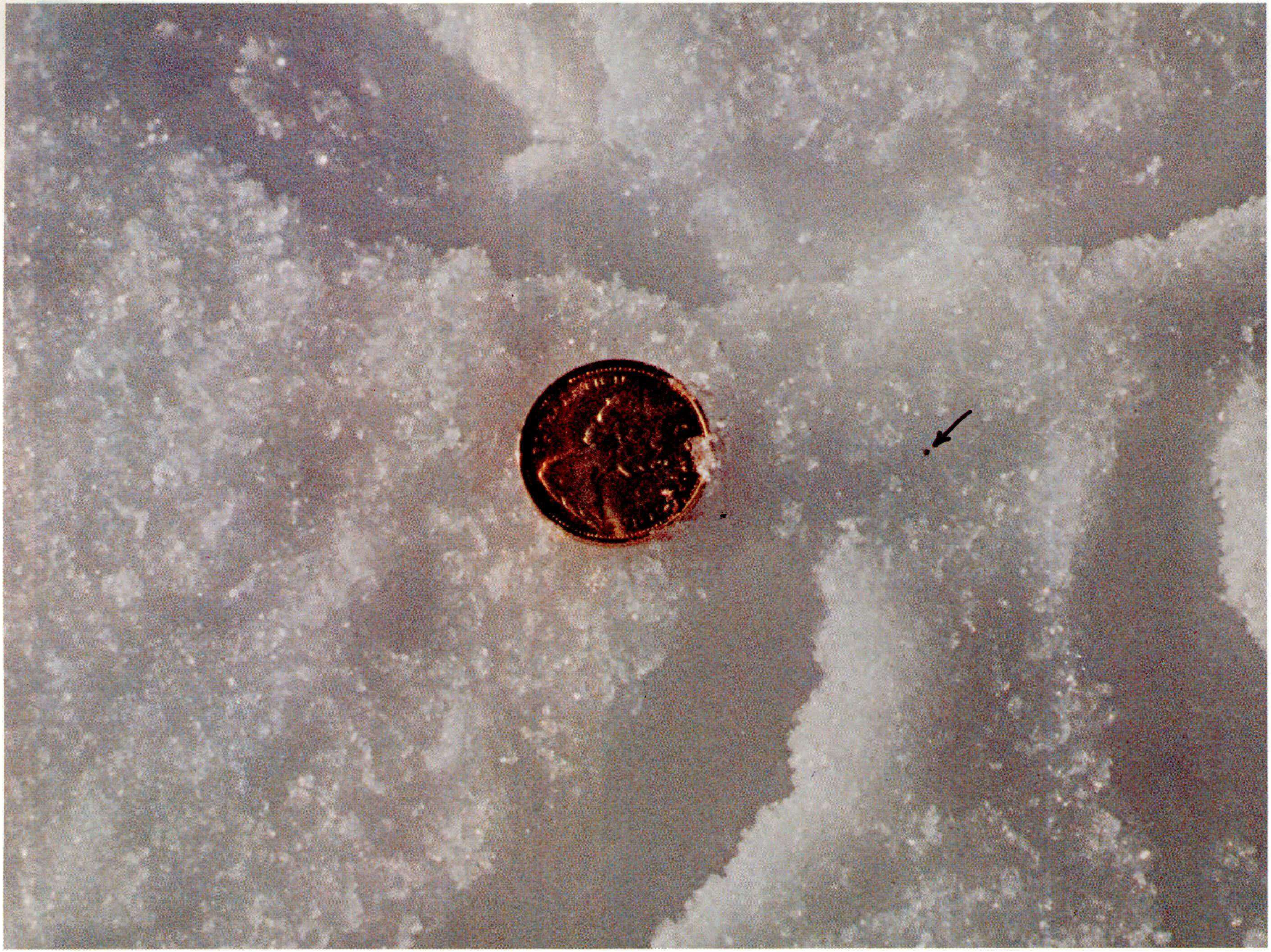

FIGURE 19 The minute size of particles is exemplified by this photograph in which a Canadian one-cent piece provides the contrast with a single particle to its right.

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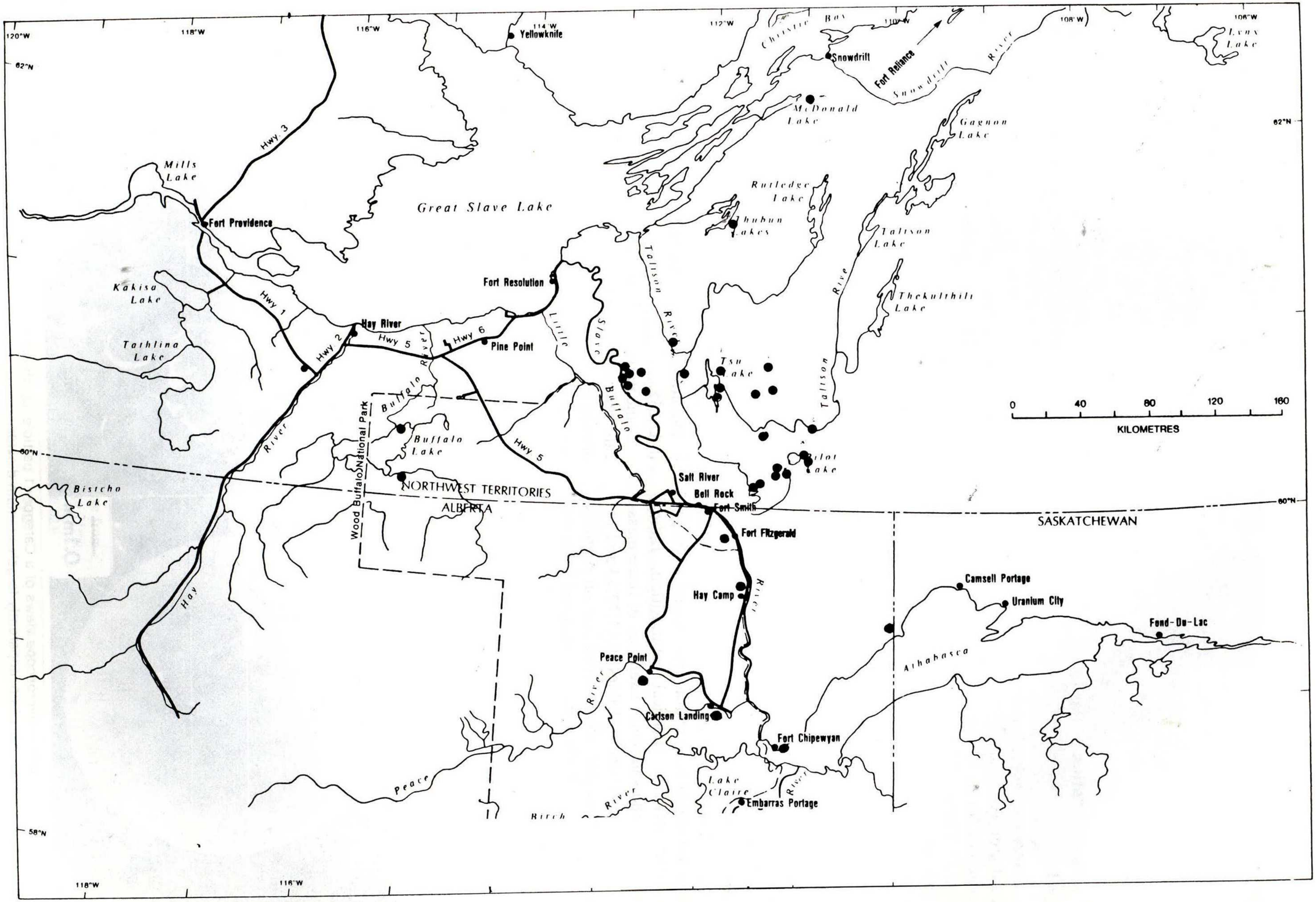

FIGURE 20 Location of particles found during ground surveys of remote sites in Phase II. Map prepared by James F. MacLaren Ltd. (reference 1).

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APPENDIX D provides a record of particles found in communities, on highways and on or around various lakes. Details of ground searches in Phase II are given in the MacLaren report (1).

7.3.2 Characteristics of Particles

General

There were two quite distinct types of particles. The dominant group consisted of small, high density spheres and accounted for by far the bulk of the particles recovered overall. These will be referred to as Category 1 particles and are easy to define. The other group, Category 2, comprises a variety of particles. Many were flaky, thin, friable, curved or twisted; others were smooth, round or oval, but low-density in comparison with Category 1 particles and somewhat larger in size at the same location. The flaky ones were easily determined in the field to be unlike the Category 1 particles, but the density distinction was only discovered by examination in the WNRE laboratories.

Of about 4000 particles recovered, approximately three hundred were individually examined at WNRE and NHW for one or more characteristics such as shape, weight, size, density, chemical composition, radionuclide content and solubility. Examples of these measurements are summarized in Tables 10,11,12,13 and 14. Almost all of these tests were carried out on particles recovered during the winter; the few analysed from the summertime recoveries yielded little new information. The results of these tests were used to help define the hazards that similar particles presented, the number of particles in a given area (and their mass and amount of activity), and the area over which such particles might have spread.

Chemical Composition

Many recovered particles were analysed by a variety of techniques to determine their chemical composition, showing the two categories to differ sharply.

A scanning electron microscope photograph of a Category 1 particle recovered from Snowdrift is shown in Figure 21. The photo on the left shows the outer surface of the particle. In the right-hand view the particle is shown to possess a crystalline outer layer, which has been analysed as uranium dioxide (UO_2) and which is clearly distinct from the substrate. Figure 22 shows a cross-section through such a particle along with elemental maps of uranium and molydenum in which the white areas indicate presence of the element being mapped. These show a high concentration of uranium and absence of molybdenum in the outer layer, consistent with its identification as UO_2. The metallic core beneath this layer is apparently made up of a variable uranium/molybdenum alloy containing 5-15% or more molybdenum (and possibly some oxygen). Dendrites of essentially pure molybdenum are visible at the centre of the particle. Their presence confirms that these particles have solidified from a uranium-molybdenum melt, indicating that they have survived a very severe thermal excursion, which has obscured their original form.

The uranium was found to be enriched to nearly 90% in U-235.

Some particles of the second category contain significant amounts of uranium (but less than Category 1), alloyed primarily with the components of stainless steel (nickel, iron, chromium, etc). In addition, significant amounts of niobium and tantalum have been detected in some particles. It was found in subsequent examination of a single spherical low-density particle, i.e. not a Category 1 particle, that no oxygen, carbon or nitrogen was combined with uranium, but that much beryllium was present.

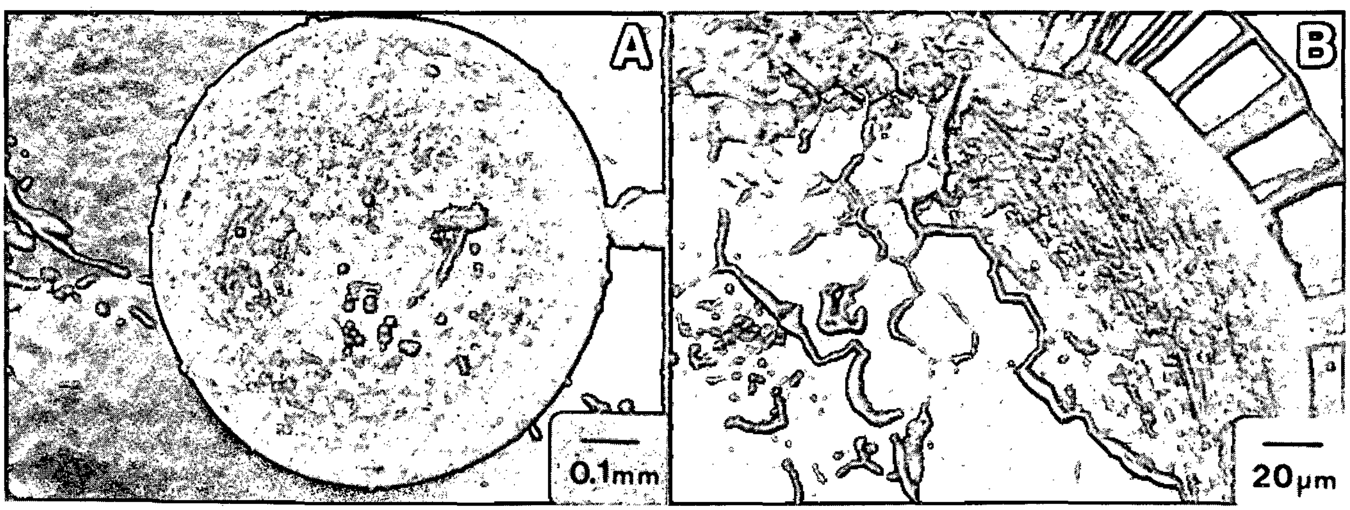

FIGURE 21 Scanning electron microscope views of a Category 1 particle. (a) shows surface texture; (b) shows that the surface represents an outer skin, apparently largely uranium dioxide.

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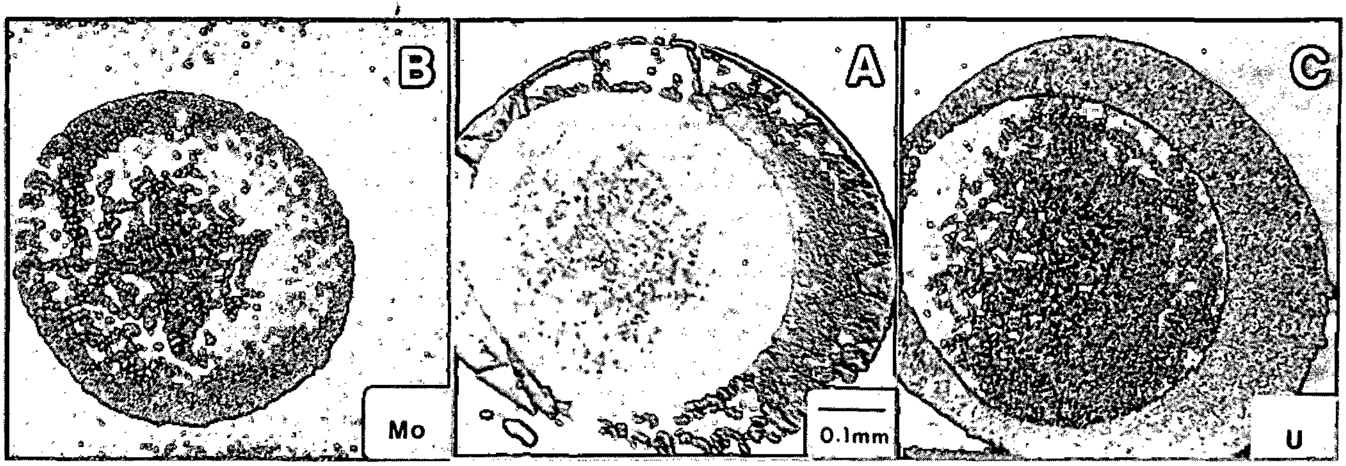

FIGURE 22 (a) is a polished section of a particle showing the core-and-rim structure; (b) shows the distribution of molybdenum (white), essentially only in the core of the particle, and (c) shows the distribution of uranium (white). These are X-ray fluorescence element maps.

TABLE 10

Average Dimensions and Activity of Particles Recovered from Various Locations

Location	Particle Category	Number of Particles Examined	Average Mass (mg)	Average Radius (mm)	Average activity (Curies/gram)	Counting date
Snowdrift area	1 (high density)	12	2.3	.380	—	—
	2 (lower density)	2	2.6	—	—	—
Pine Point area	1	2	0.145	0.145	0.8	14 March 1978
Hay River area	1	8	0.370	0.210	0.4	30 March 1978
	2	15	0.750	0.350	0.1	30 March 1978
Fort Resolution area	1	64	0.22	0.170	0.5	20 March 1978
	2	28	1.0	0.350	0.1	20 March 1978
Pilot Lake grid	1	35	0.015	not measured	0.7	9 March 1978
	2	included in above — no density measurement possible				
Rutledge Lake	1	3	0.093	0.128	0.5	8 May 1978
	2	3	0.3	0.4	0.04	8 May 1978
Tsu Lake	1	10	0.04	0.095	0.5	8 May 1978
	2	9	0.07	0.150	0.3	8 May 1978
Central Great Slave Lake	1	5	1.1	0.286	0.25	10 May 1978
	2	1	2.1	0.468	0.002	10 May 1978
Buffalo Lake	1	10	0.09	0.120	0.3	14 April 1978
	2	14	range from .1 to 21mg	—	0.1	14 April 1978
Fort Smith area	1	3	0.023	0.08	0.05	2 May 1978
	2	1	0.035	—	0.2	2 May 1978

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TABLE 11

Individual Radionuclide Activities for a Sampling of Particles

Location and counting date	Particle Identification[1]	Particle Category	Particle Mass (mg)	Specific Activity (millicuries per gram)								
				Zr-95	Nb-95	Ru-103	Ru-106	Ce-141	Ce-144	Sr-89	Sr-90	Others
Pine-Point 14 March 78	X0199-W3-1	1	0.148	170.	290.	150.	N.D.[2]	N.D.	N.D.	N.M.[3]	N.M.	N.D.
Hay River Area 30 March 78	X0046-W2-1	1	0.365	150.	230.	85.	10.	N.D.	N.D.	N.M.	N.M.	N.D.
	X0046-W2-6	2	0.598	35.	38.	6.2	N.D.	16.	13.	41.	1.3	La-140: 5.4 Co-58: 0.3
Fort Resolution 20 March 78	X0161-W1-7	1	0.188	250.	410.	190.	N.D.	N.D.	N.D.	N.M.	N.M.	N.D.
	X0161-W2-2	2	0.584	2.5	2.7	0.2	N.D.	1.6	1.1	N.M.	N.M.	La-140: 0.1
	X0161-W3-10	1	0.170	140.	240.	130.	N.D.	N.D.	N.D.	N.M.	N.M.	N.D.
	X0161-W4-1	1	0.193	135.	270.	160.	19.	N.D.	N.D.	N.M.	N.M.	N.D.
	X0161-W8-1	2	0.739	27.	35.	15.	N.D.	13.	8.1	N.M.	N.M.	Co-58:1.1
	X0048-W14	2	1.456	14.	20.	7.5	N.D.	5.4	N.D.	.05	.003	Co-58:0.8
Pilot Lake 9 May 78	X0366-W4	1	0.019	130.	260.	95.	19.	N.D.	N.D.	.007	.0004	N.D.
		1	0.024	38.	65.	22.	5.4	N.D.	N.D.	N.M.	N.M.	N.D.
Tsu Lake 8 May 78	X0304-W7	1	0.041	150.	300.	100.	27.	N.D.	N.D.	N.M.	N.M.	N.D.
	X0304-W12	2	0.089	38.	60.	60.	N.D.	27.	54.	12.	0.7	Co-58:0.2
Simpson Island 5 May 78	X0187-W3	1	0.978	90.	190.	75.	15.	N.D.	N.D.	N.M.	N.M.	N.D.
	X0187-W4	2	2.620	3.0	5.4	1.3	0.5	0.32	0.5	N.M.	N.M.	Cr-51:0.3 Co-58:0.5 Fe-59:0.02
	X0187-W5	2	2.082	2.4	4.3	1.2	0.3	0.30	0.5	.006	.0003	Co-58:0.8
Buffalo Lake 14 April 78	W15	1	0.082	54.	81.	25.	trace	N.D.	N.D.	N.M.	N.M.	N.D.
	W23	2	0.153	60.	110.	11.	N.D.	120.	110.	38.	1.2	
Fort Smith Area 2 May 78	W1	1	0.026	140.	235.	50.	8.1	N.D.	N.D.	N.M.	N.M.	N.D.
	W3	2	0.035	51.	70.	0.3	N.D.	23.	35.	N.M.	N.M.	La-140:0.01

[1] The first part of this code is the number of the seal on the shipping container; the last two terms are Whiteshell codes under which the particles were analysed.
[2] N.D. = not detected (looked for, not found)
[3] N.M. = not measured, but may or may not be present.

Density

The difference in density between the two categories was referred to in Section 7.3.2. The U/Mo spheres have densities in the range 8-18 grams per cubic centimeter averaging about 10. Because of their irregular shape the densities of the category 2 particles were much more difficult to determine. However, some of the more spherical ones were measured and showed densities in the range 2-6 g/cm^3 with an average of about 4 g/cm^3. The high density spheres comprise more than 80% of the particles studied.

Size and Weight

At any one location, the size and weight of the Category 1 spheres was remarkably uniform (Figures 23 and 24). The less regular and lower density particles found at the same location were, in general, larger (Figure 25). The most flake-like of these were often relatively quite large, measuring several millimeters on a side, but very thin. This variation is consistent with the ballistic behavior of these various shapes and densities.

The size and weight varied markedly with distance from the trajectory. As the particles formed and fell from the burning and disintegrating core, presumably at altitudes of 40-50 kilometers, they were carried southward by the wind. The larger, more streamlined and denser particles were least affected; the smaller ones were carried quite long distances from the original flight path. For Category 1 particles, the diameters range from a maximum of about 1.0 mm near the trajectory down to 0.1 mm or less in the most southerly areas; the corresponding masses range from a few milligrams down to a small fraction of a milligram. The regularity of the variation of particle size with distance from the trajectory is shown in Figure 26. This figure indicates, by extrapolation, that any particles which proceeded further south than the indicated boundary would be less than about 100 micrometers in diameter.

The masses of the Category 2 particles varied over a somewhat wider range and being so irregular in shape their sizes are difficult to characterize.

Radionuclide Content

The two categories of particles are also distinctly different in respect of their radionuclide content. As Table 11, shows, Category 1 particles contain only the fission

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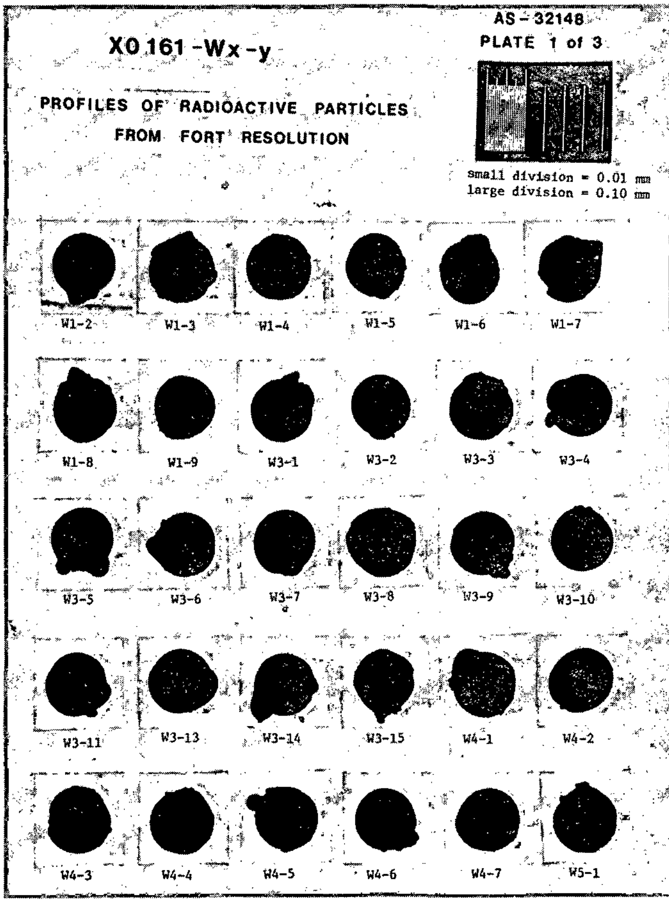

FIGURE 23 Silhouettes of Category 1 particles from Fort Resolution. W1-2, W1-3, etc., are WNRE laboratory numbers.

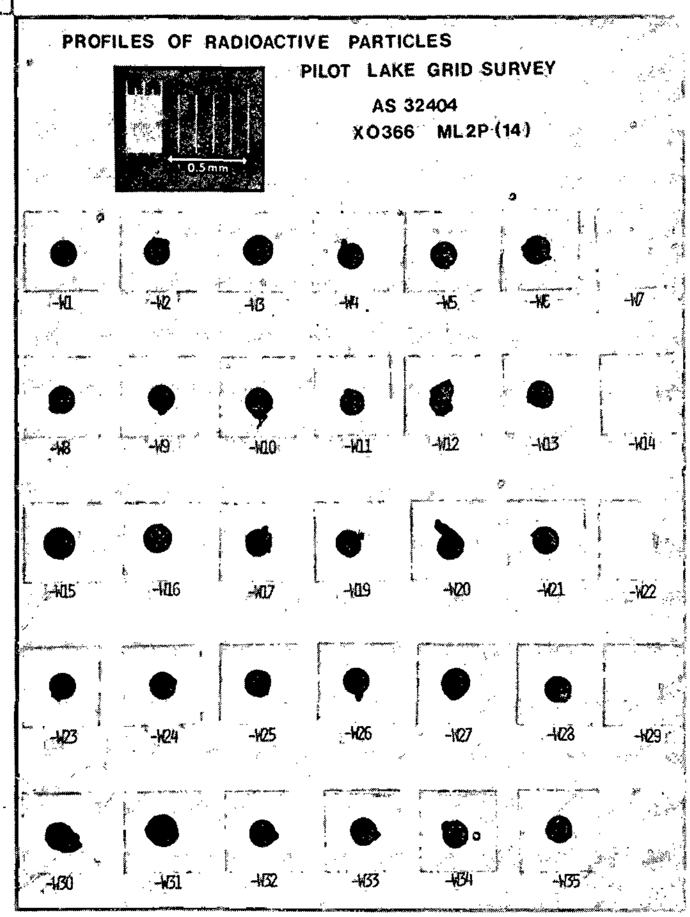

FIGURE 24 Silhouettes of Category 1 particles from the frozen surface of Pilot Lake, a short distance northeast from Fort Smith and a much longer distance south of Fort Resolution.

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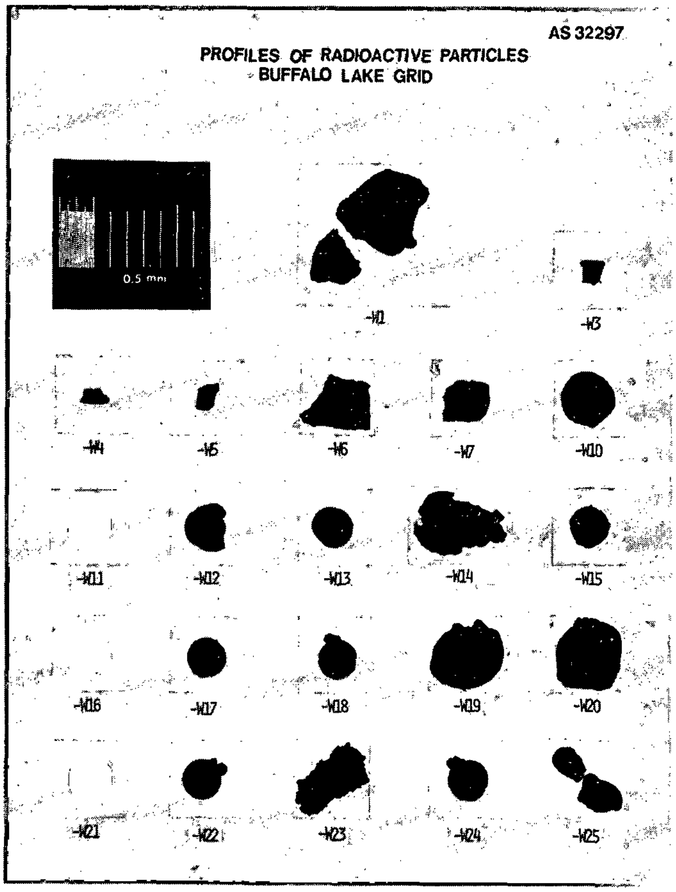

FIGURE 25 Silhouettes of particles of both categories from the frozen surface of Buffalo Lake.

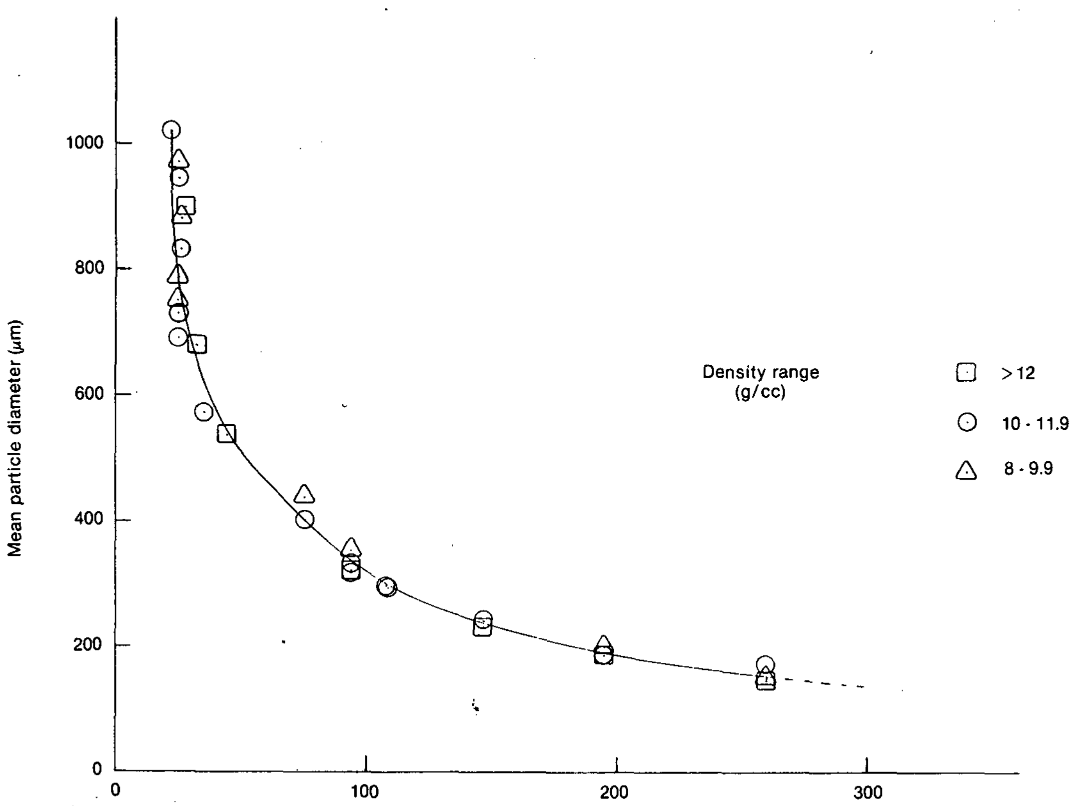

FIGURE 26 Mean particle diameter versus distance from re-entry trajectory.

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products Zr-95, Nb-95, Ru-103 and -106 at significant levels, and traces of Sr-89 and -90. Since all but the strontium are highly refractory (high melting point and low vapour pressure) elements, it would seem that the melting of this material has also driven off the bulk of the more volatile fission products such as Cs-137, Ce-141 and -144 and Sr-90.* The specific activity of these particles was apparently independent of their size and/or location. On April 1, 1978, the average specific activity was about half a curie per gram. Table 12 illustrates the rate of disintegration of radionuclides in such particles, using Zr-95 and Ru-103 as examples. Sr-90 data are also included for contrast — this isotope has a half-life of 29 years and the data show its much slower rate of decay; they also show that rather little Sr-90 was encountered on the ground. It can be noted that Zr-95 and Ru-103 (along with Nb-95, which is both a fission product and a daughter of Zr-95) are the source of most of the gamma radiation in Cosmos particles.

Category 2 particles contained a much wider variety of radionuclides. In addition to the Category 1 fission products they contained Ce-141 and -144 in large amounts, more significant amounts of Sr-89 and -90 and a variety of activation products of stainless steel: Cr-51, Mn-54, Co-58 and -60 and Fe-59. Ta-182 was also detected in some samples. Table 11 shows that the specific activity of these particles was about a factor of 5 less than that of Category 1 particles.

During the summer Phase, field measurements of size and radioactivity level confirmed the relation between and the decrease in both parameters as distance south of the trajectory increased (Table 13). Many tiny particles in Fort Smith in the summer were indiscernible against background at 1 meter, so by themselves had very low readings — less than about 5 μR/h. APPENDIX D provides data on many particles, and the following data illustrate the variation in radioactivity level in over 3000 particles recovered from the main communities during Phase II. The values are all given in μR/h at 1 meter, and the reader should realize that the exposure rate at 1 cm is about 10,000 times larger in each case. Below background, 200 particles; up to 10 μR/h, 989; 11-20, 1226; 21-30, 495; 31-40, 94; 41-50, 19; 51-60, 12; 61-70, 2; 71-80, 2; 81-90, 0; and 91-100 μR/h, 1. There were also flaky particles at 150 (2 particles) and 225 μR/h at 1 meter (1 particle).

Solubility

In order to assess the hazard that these particles presented to humans and the environment, a number of representative particles were subjected by both WNRE and RPB to solubility measurements in hot and cold

* As Table 10 shows, the strontium is present at very much lower levels than the zirconium-95, etc. Because it is a beta-emitter, strontium was analysed for by a different technique. Thus, it was detected at levels at which other gamma-emitting radionuclides would not be noticed.

TABLE 12

Activities of some Fission Products at Different Dates

(millicuries per gram of as-recovered particle)

Isotopes	24 Jan '78	1 Apr. '78	1 Aug. '78	June '79	June '80	June '83
Zr-95 (64 d)	400	200	55	8	0.17	$2x10^{-6}$
Ru-103 (39.4d)	400	120	14	.6	.001	$5x10^{-11}$
Sr-90 (29 yrs)	.5	.5	.49	.49	.47	.44

Note: Zr-95 and Ru-103 are major contributors in Category 1 particles. The data for these two for 1 April, 1978 are averages of WNRE data on over 100 such particles on or about that date; figures for other dates are calculated from the appropriate half-lives. The Sr-90 values come from the average of all measurements on particles of both categories.

TABLE 13

Variation in Diameter and Radioactivity* of Particles, with Distance South of Trajectory

Location	Diameter of Particles	Radioactivity (μR/h at 1 meter)
Snowdrift	1.1 mm	30
Hay River	0.7	19
Fort Smith	0.4	10
Fort Chipewyan	0.4	less than background

*Meter readings — uncorrected for background

water and in simulated stomach acids. Table 14 presents data from these tests.

These solubility tests have shown that, for the most part, the particles are of very low solubility. The Category 1 particles can be described as virtually insoluble. A few of the Category 2 particles, however, did display slight solubility in simulated stomach acids (about 1% dissolved in biologically relevant dissolution times). A single sample was found to be fairly readily soluble (up to 30%) in hydrochloric acid. This result represents one large, fragile flake, and may possibly not indicate true solubility but rather a suspension of fine particulates broken away from the major piece. Nevertheless, its biological effect may not be very different from that of a soluble particle. Fortunately, this type of particle was not common and could be no more than a few percent of all particles.

8. Source Term Estimates

The "source term" is defined as the inventory of both radioactive and toxic materials contained in the satellite at the time of re-entry. Clearly, to evaluate and deal with the hazard posed by Cosmos 954, a reasonable assessment of this inventory is needed. However, because the launching nation provided little detailed

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TABLE 14

Solubility of Recovered Particles (Selected Data)

Particle Identification	Particle Category	Measuring Laboratories	Test Conditions	Time (Hours)	Range of Solubilities of Individual Radionuclides (%) Most Soluble	Least Soluble
Ft. Resolution X0161-W6-2 (Phase I)	1	RPB	Hydrochloric Acid pH of 1 @ 22°C	17	2.3×10^{-2} (Ru-103)	4.0×10^{-4} (Nb-95)
				154	2.9×10^{-2} (Ru-103)	7.0×10^{-4} (Nb-95)
				605	6.6×10^{2} (Ru-103)	2.3×10^{-3} (Nb-95)
Ft. Resolution X0161-W3-11 (Phase I)	1	RPB	Distilled water 22°C	23	5.0×10^{-4} (Nb-95)	1.0×10^{-5} (Zr-95)
				305	2.0×10^{-3} (Nb-95)	2.0×10^{-5} (Zr-95)
Ft. Resolution X0161-W8-3 (Phase I)	1	RPB	Distilled water 100°C	47	6.0×10^{-5} (Ru-106)	9.0×10^{-6} (Zr-95)
				355	2.0×10^{-4} (Ru-106)	4.0×10^{-5} (Zr-95)
Ft. Resolution X0161-W8-16 (Phase I)	1	RPB	Melted Snow from NWT 22°C	19	7.0×10^{-5} (Ru-103)	not detectable (Zr-95, Nb-95)
				109	6.0×10^{-4} (Ru-106)	2.0×10^{-4} (Zr-95, Nb-95)
Hay River Cs-13-G-16 (Phase II)	2	RPB	Hydrochloric acid pH 1 @ 22°C	6	4.5×10^{-3} (Ce-144)	2.1×10^{-4} (Zr-95)
				72	1.1×10^{-2} (Ce-144)	1.1×10^{-3} (Zr-95)
				240	2.2×10^{-2} (Ce-144)	3.6×10^{-3} (Nb-95)
Hay River Cs-13-G-50 (Phase II)	2	RPB	Hydrochloric acid pH 1 @ 22°C	6	6.1×10^{-4} (Ce-141)	2.1×10^{-4} (Zr-95)
				72	4.3×10^{-3} (Zr-95)	7.1×10^{-4} (Ce-141)
				240	1.6×10^{-2} (Zr-95)	2.4×10^{-3} (Ce-141)
Hay River Cs-13-G-11 (Phase II)	2	RPB	Hydrochloric acid pH 1 @ 22°C	6	1.4×10^{-1} (Ru-103 and -106)	1.8×10^{-3} (Nb-95)
				240	1.5 (Ru-106)	1.2×10^{-2} (Zr-95)
Hay River X0046-W4-1 (Phase I)	2	RPB	Hydrochloric acid pH 1 @ 22°C	5	1.6 (Zr-95)	0.2 (Ru-103)
				45	2.6 (Zr-95)	0.2 (Ru-103)
				188	3.0 (Zr-95)	0.3 (Ru-103)
Rutledge Lake W-2 (Phase I)	2	RPB	Distilled water 22°C	5	nothing detectable	—
				25	nothing detectable	—
				187	4.7×10^{-3} (Nb-95, Zr-95)	nothing detectable
Pine Point Cs-13-G-341) (Phase II)	2	RPB	Hydrochloric acid pH 1 @ 22°C	17	29.5 (Ru-103)	4.0 (Ce-141)
				143	30.9 (Ru-103)	4.3 (Ce-141)
Ft. Resolution X0161-W8-7 (Phase I)	2	WNRE	Distilled water @ 22°C	7.5	2.6×10^{-3} (Nb-95)	ND (Zr-95)
				584	1.6×10^{-1} (Nb-95)	3.8×10^{-2} (Zr-95)
Ft. Resolution X0161-W3-7 (Phase I)	1	WNRE	Distilled water @ 100°C	7.5	5.5×10^{-4} (Nb-95)	nothing else detected
				584	1.2×10^{-1} (Nb-95)	2.2×10^{-2} (Zr-95)

information about the satellite and its design, the "source term" can only be estimated. While rough estimates of the inventory of fission products have been derived, nothing can be concluded with respect to the total amount of activation products (and toxic materials) except by inference from materials recovered.

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In the first attempts to estimate the fission product inventory of Cosmos 954, calculations were based on the design features of an early Russian space reactor, Romashka, of which some details were published in the open literature in 1964 (8).

However, recovered debris soon showed that the reactor on Cosmos 954 was not similar to the Romashka design. Since a knowledge of the power level is necessary in order to calculate the total fission product inventory, considerable effort was expended to arrive at an independent means of estimating it. The only information available that could provide a lead in that direction was the concentration of fission products contained in recovered fuel particles. If plutonium (Pu) were present, as an activation product from neutron capture by U-238, its concentration would also be useful, and a single determination was therefore carried out.

The number of fission events per unit weight of fuel was calculated on the basis of the following information and assumptions:

i) The Pu-239 content in the core at re-entry was assumed to be 5.9 ± 0.6 x 10^{-6} grams per gram of uranium. (This value was obtained from the single plutonium analysis of one fuel fragment).
ii) The average Zr-95 specific activity in recovered fuel fragments was approximately 0.1 Ci/g on April 1, 1978; for Ru-103 the corresponding value was 0.05 Ci/g. These values are rough averages from several hundred fuel fragments.
iii) The average uranium content of fuel particles was of the order of 80% and this was enriched to nearly 90% in U-235. These results were averaged from a number of determinations.
iv) Recovered fuel particles were assumed to be representative of the original intact core.
v) The Cosmos 954 reactor was assumed to have a fast neutron spectrum. This is consistent with some of the activation product yields and is implied in Russian comments. An average neutron energy of 1 MeV was assumed for determination of the absorption and fission cross-sections of U-238 and U-235.
vi) The reactor was assumed to have operated continuously from launch to re-entry, i.e. 128 days.

Calculations based on the above yield the following results for the three species referred to:

i) from Pu-239 — 1.6 x 10^{18} fissions/gram of uranium
ii) from Zr-95 — 2.1 x 10^{18} fissions/gram of uranium
iii) from Ru-103 — 2.9 x 10^{18} fissions/gram of uranium

Taking the average value for burn-up as 2 x 10^{18} fissions per gram of uranium, a specific power of approximately 5 W/g of uranium was derived. A minimum fuel mass can be estimated from consideration of the amount needed to achieve criticality. For a fast reactor with a thick beryllium reflector and high uranium density, a critical fuel mass of at least 18 kg of highly enriched uranium is indicated. Assuming a value of 20 kg, the power for Cosmos 954 would be of the order of 100 kW, and, using an existing computer program (FISSPROD) at AECL's Chalk River laboratories, the fission product activity at shutdown was calculated to be about 500,000 curies. These calculations are not without considerable uncertainty; however, this is the best estimate that has yet been derived. The fission product inventory and its decay with time is shown in Figure 27. Note that the initial decay rate is extremely rapid, because many of the fission products have short half-lives. After one year, according to this curve, only one two-hundred-and-fiftieth (1/250) of the original inventory exists, after two years about one seven-hundredth.

The inventory of *activation* products is unknown since neither the mass of structural material nor the neutron flux to which it was exposed can be determined. However, it can be stated with near certainty that it will be but a small fraction of the fission product inventory.

9. The Question of Unrecovered Material

9.1 General

The description and characterization of recovered material in Section 7 allows the nature of the hazards posed by the debris from Cosmos 954 to be described. However, the degree of the hazard (the "risk") must be evaluated on the basis of the amount of similar material which remains in the environment. With completion of the search and recovery program, a major objective has been to provide an estimate of the amount of unrecovered material.

The inventory of hazardous material on board at re-entry has been defined as best as possible in Section 8, but the assessment of risk is complicated because there is no way of knowing at the present time how much material was "burned up" during re-entry and remains suspended in the upper atmosphere in the form of minutely divided "dust" particles. Therefore, the best estimate of the amount of radioactive material which reached the ground can be gained by extrapolation from what was recovered.

9.2 Larger Fragments

The foregoing limitations apply especially to any attempt to estimate the number and activity of larger fragments which remain undetected. These larger fragments would be predominantly associated with the structure, rather than the core, of the nuclear reactor, with much of their activity arising from the decay of activation products. Obviously little can be said of what

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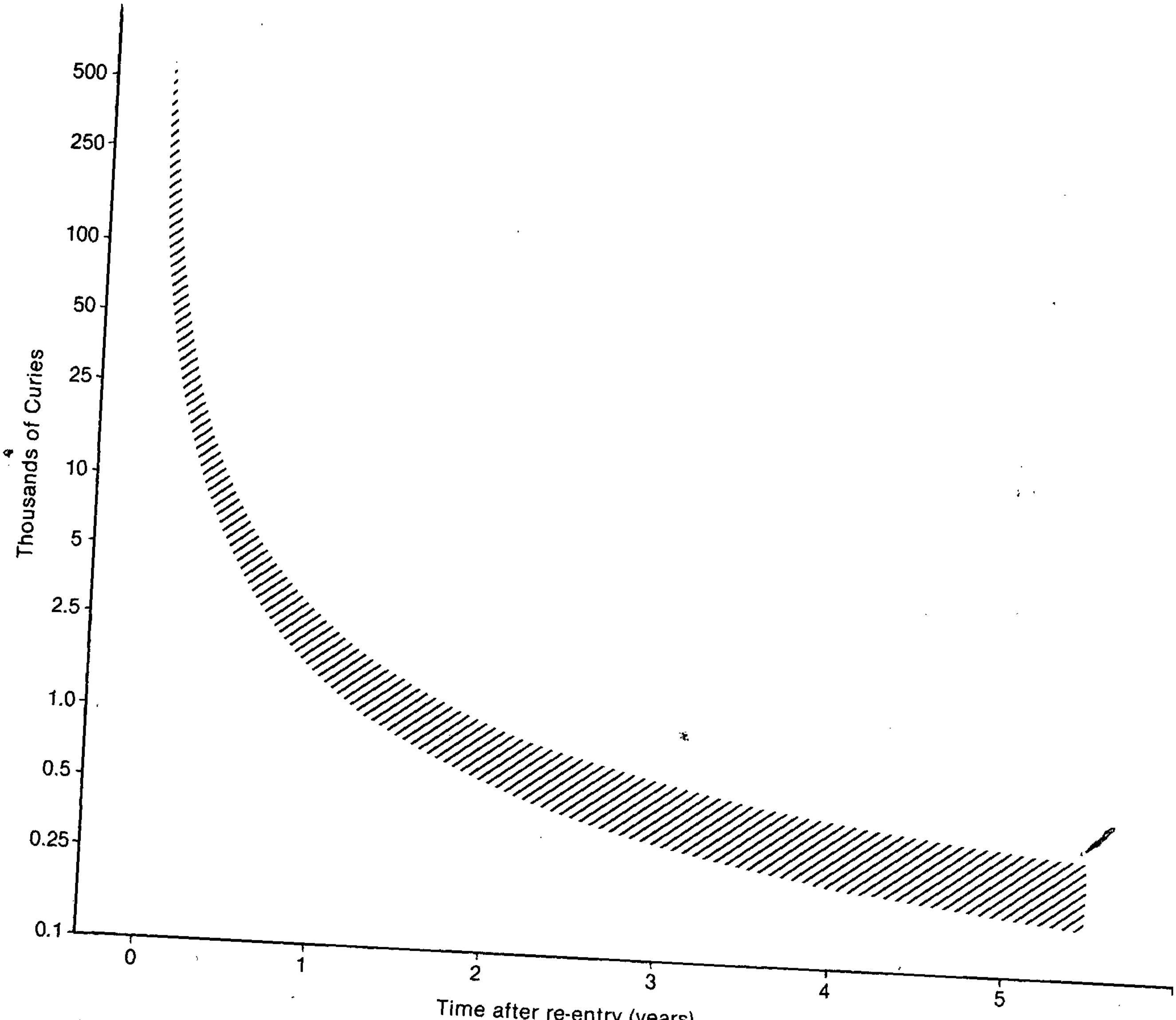

FIGURE 27 Approximate range of fission product activity from Cosmos 954 debris, and its decay with time.

was initially present let alone what might have reached the ground.

Another approach is to consider what might have been missed by the search technique. The probability of detecting a radioactive fragment using an air-borne gamma search technique is a function of a large number of parameters including detector characteristics, air-frame speed and altitude, spacing of flight lines, snow and ice cover, atmospheric conditions, background radiation, operator skill and, of course, the activity level of the fragment. It has been determined that for the wintertime search conditions and the C-130 search parameters, the most highly active fragment which would have been missed, if all conditions conspired against detection, would be of the order of 150 mCi (i.e. one which would exhibit an exposure rate of about 300 mR/h at a distance of one meter). On the other hand, fragments with exposure rates down to about 10 mR/h at one meter were detected during that phase of the search; this can perhaps be regarded as a lower detectability limit under favourable conditions. The exact relationship between activity and probability of detection between these limits would be very difficult to derive. However, it is known that the relationship is not linear; the detection probability increases rapidly as the activity increases above the lower limit such that objects midway between the limits discussed would have a detection probability well in excess of fifty percent.

As an additional aid to interpreting what the search may have missed, parts of the area were subjected to the closer scrutiny of helicopter-borne equipment (detection sensitivity increased over that of a Hercules by a factor of about four). For example, during the winter an area about 9 km by 8 km, spanning the trajectory just east of Artillery Lake, produced no "hits" in the original search by Hercules although it was considered on the

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basis of ballistic calculations to be a prime area for larger objects; likewise none were found in a subsequent helicopter re-survey.

On the other hand, another search along two flight lines passing through the area where the largest number of fragments had been recovered turned up two additional beryllium cylinders. During the summer, searches by a detector-equipped helicopter and DC-3 in the area where the bulk of the beryllium rods had been found in the winter recovered ten new "hits" including seven additional rods.

In the light of this somewhat conflicting information, statements with regard to the amount of material left in the environment must be cautious ones. It is almost certain that all fragments with activities greater than 150 mCi would have been found during the wintertime search, but it must be admitted that few fragments of less than about 5 mCi (as of the search date) would have been "spotted" from C-130s. However, reflights of selected areas do indicate that there can not be large numbers of large fragments still lying about.

Confirmatory information provided by the USSR is of interest in this discussion. When advised of the recovery of the beryllium fragments, the USSR stated that of six moving elements in the satellite's beryllium reflector all had been found, and that of several tens of beryllium rods most had been found. Since at that time only 34 had been recovered, with the final total at 41 it may be presumed that few are unaccounted for if indeed they landed.

At time of publication of this report, all unrecovered objects will have decayed to a few percent of the activity existing during the 1978 wintertime search; the vast majority will be much less than 1 mCi. Further, after break-up in the spring of 1978 any unrecovered fragments lying on ice would have sunk to the bottom of lakes and rivers, where they would present a much reduced environmental hazard.

9.3 Small Particles

Estimates of the amount and distribution of unrecovered fuel particles from the reactor core are somewhat better defined than those for large objects. It should be borne in mind that the approach to the clean-up of the two-classes of debris was fundamentally different. For the larger fragments, the goal was removal of all highly radioactive material from the environment; for the fuel particles (once it had been concluded that no major portions of the reactor core had survived intact) the goal was to remove them from inhabited and frequented areas. Since these areas form only a small part of the total area affected, most of the core material which reached the ground remains in the general environment. Its possible behaviour there will be considered later.

On the assumption that the core consisted of about 20 kilograms of U-235, and reactor power of the order of 100 kW, as of 1 April, 1978 the total fission product inventory would have been of the order of 13,000 Ci. Not all of this material and its associated activity reached the ground, however. High altitude air sampling carried out by the Environmental Measurements Laboratories (9) of the U.S. Department of Energy in June and September, 1978 over Alaska confirmed the presence of significant concentrations of 90%-enriched U-235 in the upper atmosphere between 30 and 40 kilometer altitude. Their conclusion is that this material is from Cosmos 954. No estimate of the amount of material so suspended has been made since the volume of atmosphere so affected is not known. However, the results are compatible with a significant fraction of the Cosmos 954 core having remained air-borne. More thorough sampling was carried out in the spring of 1979 by which time the material had descended to altitudes attainable by aircraft, however, results were not available at time of writing. The indication is that Cosmos 954 products are now mixed with material from atomic bomb testing. Suspended core material will eventually settle on the ground but over a very large area (similar to the fallout from weapons testing), and one which may of course be remote from the Great Slave Lake area.

These considerations alone then, do not lead to a reliable estimate of how much fuel material and its associated activity reached the earth's surface following re-entry. However, two other techniques were applied to provide an improved estimate of the total mass and activity of Cosmos 954 fuel that actually reached the ground within this area.

The first of these techniques, devised by GSC (4), surveyed the total activity (in excess of background) deposited on the ice of Great Slave Lake, where interference from natural radiation from rock could be avoided. A detector-equipped helicopter flew a total of thirteen traverse lines, providing systematic coverage of the lake area (see Figure 28). Integration of the results over the entire lake surface then provided a measure of the total excess activity present as of 1 April 1978. This survey provides quite a clear picture of the distribution of activity over the lake surface prior to 1978 spring break-up. Most of the contamination was concentrated in the middle of the lake, with the eastern, northern and western reaches essentially uncontaminated. The activity fell off rapidly towards the southern shore line. The land profile insert in figure 28 highlights a significant fact: the average *natural* background activity over the uncontaminated land mass was higher than that over even the most contaminated part of Great Slave Lake. The survey also confirmed a conclusion derived from analyses of individual particles; the preponderant activity was from Zr-95, Nb-95, Ru-103 and Ru-106. The more volatile fission products such as cesium-137 and

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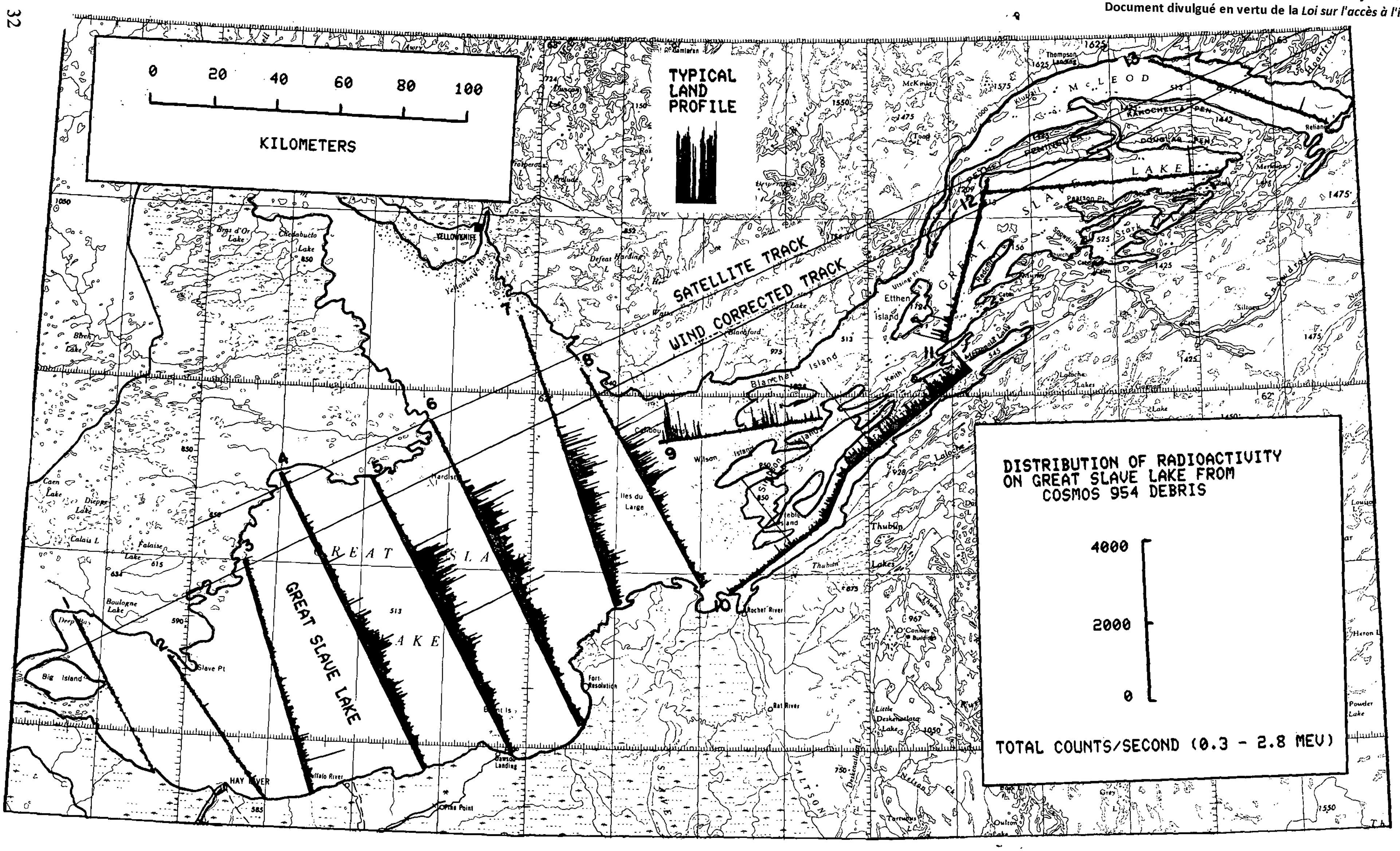

FIGURE 28. Distribution of radioactivity over frozen Great Slave Lake as of 1 April, 1978. Note that as traverse lines near the south shore the level of radioactivity decreases.

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iodine-131 were not detected nor were the many activation products which had been seen in some recovered particles.

The integration of the information from this aerial survey yields a total of approximately 700 curies of mixed fission product activity on the surface of Great Slave Lake as of April 1, 1978.

To extend this sort of information over a large portion of the estimated dispersion area, a plan was evolved by the U.S. Department of Energy to sample a number of selected frozen lakes, recovering and examining the number and characteristics of all radioactive particles within a standardized sampling grid.

Particles recovered during the sampling surveys were carefully analyzed at WNRE and the results provided much information on the variation of properties among the various classes of particles, and on particle size variation from location to location. However, the results of total mass and/or activity per unit area deduced from each sampling are so scattered that this approach was not further pursued. The wide variation probably reflects markedly uneven distribution of particles, just as found in road searches in particular, and perhaps also incomplete recovery in sampling areas. Nevertheless, the results do support the indication of a decrease in activity per unit area towards the south from a maximum in the middle of Great Slave Lake. A rough estimate of the total activity over the entire dispersion area would be of the order of 2,500 curies (as of April 1, 1978), which is compatible with the 700 curies on the lake surface alone. This represents about 20% of the calculated total inventory of the satellite at that date. The corresponding fuel mass associated with this activity would be around 4 kilograms.

As with the larger fragments, estimates of the activity remaining on the ground must allow for radioactive decay; as of January 1979 the 2500 curies would have been reduced to about 300 curies. Also it was shown that the most highly contaminated area was central Great Slave Lake. When the ice melted, all of this material would have sunk to the bottom to become incorporated in sediments.

The balance of the "source term", decayed to about 1000 curies of mixed fission products, after a year and a half, is concluded to have been trapped in the upper atmosphere. Its return to earth will be gradual and very widespread with a risk level which is very small compared to that of nuclear weapons fallout.

10. Risks to People and the General Environment

10.1 General

Fragments of significant size fell in a well-defined belt, and there is reasonable assurance that not much was missed. If there is a remaining hazard from other large fragments, it lies in that limited area and has been minimized by careful search and recovery. The particles, on the other hand, fell in great numbers over a wide and incompletely delineated area, and it is these in particular that must be considered in a review of overall environmental concerns. Again, it is the fission products that have been of concern, and have raised questions about environmental contamination with respect to fauna and flora. Due to the short life-time of the reactor, activation products, whose chief hazard would have been by external radiation if living organisms remained close to them for an extended time period, did not become a major problem.

In considering the behaviour of particles in the general environment, there are several features to be considered: their abundance; their shape, size and density which will affect their physical behaviour in water and soils; their toughness (or in some types their friability), which will affect the length of time they continue to exist as such; their solubility; and of course their content of fission products. Considering the last first, as Table 2 shows, most of the fission products possess short half-lives. The species of major concern are Sr-90 and Cs-137 with half-lives of about 30 years; these can accumulate in key tissues of living organisms (including people) — skeleton for strontium and muscles for cesium. These are among the radioisotopes that have been extensively monitored for a number of years, in connection with nuclear weapons testing, so that a data base exists for comparison with Cosmos 954 fall-out.

It has been calculated, using AECL's FISSPROD program (see Section 8) that there might have been about 50 curies each of Sr-90 and Cs-137 at the time of re-entry. If all of this activity had come to earth, by comparison with recorded fall-out records it is estimated that the total deposition per unit area would have been about one fourteenth of the amount received in the Yellowknife area in 1973 from weapons testing fall-out; that year was the *lowest* measured in 20 years of monitoring. In fact, analytical data indicate little Sr-90 and less Cs-137 in Cosmos 954 material — it is evident that only a small fraction came to earth, so that the impact on the environment of the unrecovered particles is likely to be insignificant when compared with the fall-out deposition that exists currently. Most of these two isotopes were dispersed in the upper atmosphere along with the volatile species such as iodine and noble gases, and they will contribute a trivial increment to the present inventory of such substances in the stratosphere.

Particles that fell on frozen bodies of water would eventually enter the water and settle to the bottom where, in the normal course of events, they would sooner or later become incorporated into sediments and from that point on be progressively more and more isolated from food chains. In loosely consolidated sedimentary material of similar size distribution most would tend to sink because of their high density, and their smooth spherical habit.

In vegetation on land, as snow melted and runoff proceeded during and following spring break-up in 1978, the fallen particles would soon work their way downwards becoming part of the existing mineral or organic base materials.

Townsites and frequented places were scoured to find and remove the particles; during the winter, the areas to be frequented during the 1978 Winter Games were given special attention. Particle searches were not carried out in bush, tundra, and generally unfrequented areas. It would clearly be impracticable to attempt in such areas the type of search that was made in townsites and on roads. The particles assumed to have fallen over some 100,000 square kilometers of such land and water surface must be left to be absorbed into the natural domain by settling, and long drawn-out dissolution, accompanied by radioactive decay.

There are several other encouraging features to be borne in mind when considering residual hazards from unrecovered particles. Particles will not readily become resuspended (a necessity for inhalation) under normal circumstances. Most of them were largely insoluble in simulated stomach acids, and it was demonstrated that they are still less soluble in natural water; thus movement of constituents in such waters will be limited. Most of the radionuclides present have short half-lives, so that a year after date of fall only a small fraction of their original radioactivity would have remained. The longer-lived radionuclides (particularly Sr-90 and Cs-137) are present, but in very small accounts.

It was also encouraging to the searching personnel to learn during the Phase II community searches that the areas accessible to winter search could be identified by the much reduced incidence of particles, although some additional finds were made in such searched areas (for instance in locations where snow had been piled up by ploughing).

10.2 People

In summary, the potential risks to people included external radiation to part or all of the body, and internal radiation by inhalation or ingestion.

The concern about whole body irradiation was rather soon dispelled when it became clear that the reactor core had not survived more or less intact, and that sufficiently large pieces of other radioactive material were not likely to exist. Irradiation of a significant part of the body was quite possible to persons remaining in the vicinity of significant fragments. The continued close control by health physics staff prevented exposure to search personnel. Efforts were made by the RCMP, and by officials of the NWT government and of INA, to warn trappers and hunters to avoid the vicinity of any unusual object, and requesting immediate advice of its existence. There were no confirmed reports of such finds. At time of writing, residual hazards of this nature are considered negligible.

Control over the risk of internal radiation was less possible. Ingestion was always a hazard as a result of using contaminated melted snow for cooking or drinking purposes, in spite of public cautioning against the practice in the area of concern. It was calculated that if an average particle were ingested, say in early to mid-1978, it would be capable of giving a radiation dose, mainly to the lower large intestine, roughly equivalent to that of a conventional X-ray of the gastric area. This organ would in most cases be the one affected because most particles would be essentially insoluble during passage (48 hours or less) through the body. Specific internal doses would actually be reduced if more soluble material were ingested, because soluble material would be transported to other organs in the body as well.

In this connection, water supplies from community reservoirs along the south shore of Great Slave Lake were found by RPB to show no radioactive contamination during the search periods. A further series of analyses will be carried out in 1980 of water supplies to see if any unexpected radioactivity appears.

Inhalation was improbable in Phase I since particles fell in snow and were unlikely to rise to be swept into nose or mouth. With break-up, thawing and runoff, particles would have been still less accessible to inhalation. There would have been a relation between size and potential dose — larger particles would be capable of presenting a higher dose but with little likelihood of being available for inhalation; smaller particles, with somewhat more chance of being inhaled, would present relatively inconsequential doses.

From the first stage of Phase I, all those likely to be exposed — field staff, storage crew, even air crew — carried devices to record their exposures, if any. A summary of all records is given in APPENDIX F. The total number of persons covered was 353, including all Canadian personnel and the U.S. NEST staff, and some of these were involved in both Phase I and II. Of these, 145 received a measurable dose, but the highest individual accumulated whole-body dose was 470 mrem (and so was the highest recorded skin dose), far below the maximum permissible doses for atomic radiation workers — 5000 mrem per year for whole body, 30000 mrem per year for skin.

Finally, it is worth mentioning that the winter explorers who coincidentally came upon the "antlers" on the Thelon River were quickly given a clean bill of health by medical authorities after examination.

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10.3 The General Environment

The logic applied to humans is considered to apply equally to wildlife, with respect to contact with and ingestion of debris. Unless a particle became lodged in the digestive system it would be passed in a time period that kept exposures below a hazardous level.

With respect to vegetation, wildlife personnel were at once concerned with the question of contamination of moss, on which caribou, for instance, sustain themselves essentially year round. A study carried out at the University of Toronto (10) produced evidence that moss in the debris area did not pick up radioactive contamination in the usual sense of fall-out, i.e. as very finely divided matter from air-borne vaporized fission products. Moss collected south of Great Slave Lake (and also north of the trajectory zone) led the authors of this study to conclude that fission products detected on moss samples do not exceed background levels found in the general area due to past nuclear explosion fall-out.

RPB has carried out analysis of caribou meat taken during the fall (1978) hunting season (11). These analyses showed no indication of contamination by Cosmos 954; the Sr-90 and Cs-137 levels were lower than in results obtained from meat several years previously. Samples of rain and snow from the national precipitation network, including stations in the area, were examined for gamma and gross beta radiation; RPB was unable to relate results to Cosmos 954.

The question of contamination of fish, which are so important to the region in commercial and sport fisheries and as a local source of food, has been covered by special studies at the Freshwater Institute (of DFE) in Winnipeg. In analysis of meat from 10 species of fish (592 fish taken in April, 1978, and 687 in September, 1978) fisheries experts have "not detected radionuclides derived from Cosmos 954" (12). Cs-137 alone of those to be expected from Cosmos debris was present, but at activities to be expected from global fall-out of thermonuclear bombs exploded mainly in 1959-64.

Realizing the probable spread of particles into that area, concern was raised about the breeding sites of the endangered whooping cranes in Wood Buffalo National Park. The matter was discussed with Canadian Wildlife Service personnel in Edmonton, and it was agreed to fly over nesting sites and to examine selected ground (frozen swamp) areas. This was done by a special helicopter flight with CWS personnel present. Low level flights over nesting sites did not detect any radiation. One pond in the area was surveyed on foot and no particles were found. Surveying was kept to this minimum since break-up was approaching and the cranes would soon be returning; avoiding fright to the returning birds, and damage to nests, was of paramount importance. The conclusion was that there would not be enough radioactivity from debris to cause harm to the whooping cranes by exposure, and that any particles present would settle into bottom mud and rapidly become inaccessible for ingestion.

Thus the question of environmental harm to the area affected by Cosmos 954 debris appears to be answered rather convincingly. The effects of the debris on any identified or observed part of the natural environment are considered to be insignificant.

11. Concluding Statements

Except for those tiny particles that drifted southwards, all debris fell on Great Slave Lake and on unpopulated and little frequented areas to the northeast. There is reasonable assurance that all accessible significantly-sized radioactive fragments were located and removed. Six beryllium cylinders were found; the USSR has stated that there were no more. Forty-one beryllium rods were found and the USSR said that most (of "several tens") had been found. Several were partly consumed during re-entry, thus it is possible that some never reached the earth's surface.

Debris of the order of 65 kg weight has been recovered. Of this, about 18 kg is represented by the non-radioactive "stovepipe", leaving some 47 kg of radioactive material. Almost all of this is accounted for by the "antlers", the beryllium artifacts, and pieces of steel. The proportion represented by tiny particles is minute — the 4000-odd that were recovered would weigh less than 5 grams.

The inventory of radioactivity indicates that perhaps 20% (4 kg) of the fuel came to earth. This would mean that the 4000 recovered particles represent about 0.1% of the possible total, and that the bulk of the 4 kg remained uncollected when Phase II was stopped.

Various estimates were made from actual particle recovery in specific sections of the area that indicate that the distribution of particles may be as high as several hundred per square kilometre. This is highly variable, since distribution has been shown to be uneven. Two hundred and fifty per square kilometre is equivalent to one particle every 4000 square metres.

Granted that such figures can only be approximate, they do place some perspective on such statements as the claim quoted in the press that the ground was left "littered" with radioactive particles. They also support the belief that much remains in the upper atmosphere as a result of the burn-up that indeed the USSR expected. This is presumably where the bulk of the more volatile fission products rest; they were not found on land. It appears likely that most of the strontium and cesium fission products are also still in the upper atmosphere. After nearly two years, because of atmospheric movements and mixing since re-entry, it will not be possible

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to identify these particular isotopes in the upper atmosphere or in fall-out with any assurance that they relate to Cosmos 954. The key to the existence of Cosmos 954 dust in the upper atmosphere is the presence of 90% enriched U-235, as found by balloon sampling in 1978(9).

In the early stages of the search and recovery operations it was impossible to claim that dangerously high radiation might not exist on large fragments not yet found, or that all of the particles were likely to be as small and relatively low in radiation level as was eventually learned. The finding of the fragment ML-3(10), with a radiation field of 500 R/h near contact, meant that search operations could not be carried out halfheartedly nor allowed to come to a stop until a measure of assurance was achieved that all possible such fragments had been located and recovered.

Search and recovery did go on until this assurance was gained and it was possible to conclude that: (1) it was most unlikely that additional fragments such as ML-3(10) could have been missed; (2) all obvious fragments had been located; (3) that although particles could indeed present a risk to people, a sufficient number had been examined to show that the risk was not great because of their size, insolubility and scattered distribution; (4) particles had been adequately recovered from frequented places; and (5) residual radiological risks from material left on the ground were fading so rapidly relative to natural background that following the cessation of Phase II no harm to people and the environment could be foreseen. On this basis, a calculated decision was made to discontinue search and recovery operations in October 1978.

It is important to realize that these statements can only be made because of the extent of the search and recovery operations, and of the thorough analysis and research that were carried out on recovered debris. This report has not been concerned with the costs of the operations, but it is mentioned here that the total cost to the Canadian Government in reaching the position from which the above statement can be made came to nearly $14,000,000.

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Appendix A

Chronology

The following dates delineate the major features of the development and extent of the search and recovery operations for Cosmos-954 remnants.

18 September, 1977	— launching of Cosmos 954
19 January, 1978	— U.S. government advises all nations potentially involved of the coming re-entry
23 January	— the AECB first learned of the possibility of re-entry over Canada, through advice from senior government officials and DND
24 January	— re-entry occurred at 0653 hours (EST) over the Queen Charlotte Islands off the British Columbia coast; glowing remnants reported over Great Slave Lake area by eye-witnesses
	— DND Nuclear Accident Support Team members from Edmonton at once went to Yellowknife to check the townsite for radiation
	— AECB advised Geological Survey of Canada (GSC) of the event and the probable need for air-borne detection assistance; GSC expert reached Edmonton
	— U.S. gamma radiation equipment and NEST personnel reached Edmonton in the evening
	— list of technical questions on nature of satellite prepared by AECB and submitted to USSR Ambassador
25 January	— first Canadian Forces Hercules air-borne with US search equipment
	— GSC equipment to Edmonton and put into operation
	— high level air sampling by U-2 and KC135 planes from US
26 January	— First AECB team (5 men) arrived in Edmonton
27 January	— first air detection of radioactivity from a fragment on Great Slave Lake near mouth of Hoarfrost River, 27 km. north of Fort Reliance
	— GSC equipment was already in use aboard a Canadian Forces Hercules aircraft. Eleven Canadian craft were in the air, and one US plane with infrared equipment
28 January	— an object (to become known as the "antlers") was coincidentally located near Warden's Grove on the Thelon River by naturalists wintering in the area. This was the farthest east find; it was also the largest remnant located
31 January	— AECB removes first piece of debris ML-5(1)
	— visual sighting and recovery of a fragment on ice of Great Slave Lake — this was the non-radioactive "stovepipe", ML-10(1)
5 February	— 250 Canadian Forces personnel and 115 US personnel were now involved. GSC and AECB personnel reached 13 and 11 respectively
7 February	— base camp established near Warden's Grove, on Thelon River, for further search in the eastern end of the landing path
8 February	— official Canadian advice through the Department of External Affairs to USSR that fragments of Cosmos 954 had been found
12 February	— first report of particles in vicinity of Snowdrift.
14 February	— detailed survey of people and houses in Snowdrift following discovery of small particles of residual core material
24 February	— most radioactive fragment, ML-3(10) picked up following its discovery on 20 February. Gamma radiation field of 500 R/h on contact.
10 March	— report from Cape Dorset, Baffin Island, of unexplained occurrence of large blocks of ice on a frozen lake, on the

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	extension of the fall-out path from Great Slave Lake
15 March	— Microwave Ranging System interfaced with GSC detection equipment
20 March	— report that there was no sign or evidence of satellite action at Cape Dorset; ice phenomenon was natural
10 April	— total flying time reached 4635 hours
18 April	— last search flights before break-up covered settlements and cabins between Fort Smith and Hay River
20 April	— Phase I shutdown
24, 25 May	— public meetings in Snowdrift, Fort Resolution, Pine Point, Hay River and Fort Providence for discussion of search program and of risks to people. Involved representatives of AECB and NHW as well as NWT and local officials.
6 July	— public meeting in Uranium City, Sask., to provide information on particles and the risk they present.
10 July	— AECB opened office in Hay River for coordination of Phase II operations
18 July	— Contractor staff began arriving in Hay river; ground survey commenced in NWT towns, roads, camps, lodges, etc.
12 September	— Search for particles extended into northern Saskatchewan and Alberta
14 October	— operations of Phase II completed

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Appendix B

Health Physics Aspects

1. Biological Effects of Radiation

Man and his environment have been exposed to ionizing radiation from natural sources since time began. However, it was not recognized that radiation could have any detrimental effect until the actual discovery of X-rays and radioactivity at the turn of the century. With increased experience, there was a growing awareness of the health hazard presented by excessive radiation exposure, an awareness stimulated by unfortunate high exposures such as those experienced by early radiologists and the radium dial painters of the 1920's. Since then radiobiology and radiation medicine have developed into major sciences which study both detrimental and therapeutic aspects of radiation.

Biological damage is a result of the ionization of atoms or molecules, a process which will disrupt cell structures or contents. This may lead to the immediate death of the cell, the inability of the cell to perform its function, or genetic damage to the cell's chromosomes causing the ultimate death of the cell or altered characteristics being "passed on" to its offspring.

The seriousness of a radiation exposure is determined by the number of cells affected and their importance to body function and reproduction. Different types of body cells or tissues vary in their radiosensitivity; muscle and central nervous system cells are relatively insensitive whereas the blood-forming and the reproductive organs are highly sensitive. Similarly, doses received by extremities are not as serious as the same dose received by such organs as the gonads, the lungs or the gastrointestinal system.

Radiation exposures are characterized by the rate at which they are received. Acute exposures are those received over a short period of time (hours or less). Exposures spread over long periods (up to a lifetime) are termed chronic. If an acute exposure is high enough, some effects may be observed; those that develop in the body of the exposed individual are termed "somatic", those that appear in subsequent offspring are termed "genetic" effects. Short-term somatic effects may be observed following an acute exposure. Externally noticeable symptoms are not apparent at doses less than 100 rem, but about one half of those exposed to 450 rem will die within 6 weeks of exposure. There are also delayed effects from both acute and chronic exposure. The most frequently observed delayed somatic effect is cancer, which may not be observed until many years after exposure. There may also be delayed genetic effects which are passed on to the succeeding generations by an increase in the natural mutation rates; these defects include deformities, susceptibility to disease, and premature death.

Cell damage is not irreversible. Regeneration or renewal of cellular structure can occur if the cell is not severely damaged. Also cells that are killed outright may be replaced by other healthy cells.

Although some controversy still persists and the relationship is not without exceptions, it is generally accepted that there is a linear relationship between absorbed dose, i.e. the energy deposited per unit mass of tissue, and the biological effect. Because this implies that any increment of radiation exposure carries with it an incremental risk, it is recommended that radiation doses be kept as low as reasonably achievable.

Dose limits applying to man-made sources of radiation in Canada are prescribed by the Atomic Energy Control Regulations (13); they do not apply to natural background or to medical exposures.

2. Types of Radiation

The four types of radiation, which might all have been encountered from Cosmos 954 debris, are as follows:

Alpha radiation: Alpha radiation is made up of relatively heavy, charged particles and, as a result, does not penetrate far in matter; in fact the range of alpha radiation in air is only a few centimetres, and it can be stopped by a single sheet of paper. As a result, alpha rays do not present any hazard while they are outside the body, but if a source of alpha rays gets inside the body, it may become more serious.

Alpha radiation is generally associated with the more massive radionuclides; the uranium that constitutes the fuel of a nuclear reactor is a weak alpha emitter.

Beta radiation: Beta radiation is also made up of charged particles, but they are very much lighter than alpha particles and have more penetrating power. The range of beta rays in air depends upon their energy but is generally measured in meters for those that are associated with fission and activation products; however, a thin sheet of aluminum or plastic, or a thin layer of water or ice, will stop these rays.

Beta radiation, due to its somewhat limited penetrating power, is of greatest concern when a radiation source is in contact with or very close to the outside of the body (in which case it will deposit most energy in the tissues closest to the surface), or when the radiation source is inside the body (in which case most energy is deposited within the organ where the radionuclides are concentrated).

Gamma radiation: Gamma radiation can be thought of as electromagnetic waves similar to X-rays; conse-

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quently, gamma radiation is much more penetrating than either alpha or beta radiation, and can travel much further. Because of its greater penetrating power, gamma is generally the most important radiation when considering the exposure of people by sources that are outside their bodies. The absorption of gamma radiation is also different from that of alpha and beta radiation; to reduce the intensity requires increasingly thicker absorbers. Typical absorbers are steel, lead and concrete, although water, in sufficiently thick layers, also makes a good shield.

Neutrons: Neutrons are produced by the fission process itself. Neutrons are also particles but carry no electric charge so that they can penetrate matter readily. They are primarily an external hazard. (Early in the Cosmos 954 search neutrons were of concern due to the possibility of discovering a major portion of the core that might still have been critical and hence producing neutrons. As already described, it became clear that the core had not survived re-entry intact, and neutrons were not detected at any time during the search.)

3. Health Physics

3.1 Radiation Protection Principles

"Health physics" comprises the body of knowledge dealing with the effects of radiation on man and his environment, and places particular emphasis on practical means for protecting both from harmful effects.

Since there is some degree of risk in all radiation, the International Commission on Radiological Protection (ICRP) has recommended that all radiation exposures from man-made sources should be justified and kept *a*s *l*ow *a*s *r*easonably *a*chievable (the "ALARA" principle, usually with the qualifying phrase "economic and social conditions being taken into account"). In keeping with this principle, there are three key steps that can be taken:

i) keep the *time* of exposure as short as possible;
ii) kept at a safe *distance* from the source;
iii) introduce some suitable *shielding* material between oneself and the source.

The matter of keeping at a safe distance requires further consideration. Exposure rates are governed by the "Inverse Square Law"; for instance, if the exposure rate at 10 centimeters is 200 R/h, then at 100 centimeters the rate is reduced not by a factor of 10 but by the square of 10, or 100, and would be 2 R/h. The effect, of course, works in reverse and the exposure rate increases very rapidly as one moves closer to the source.

3.2 Definition of Measurements of Radiation

Rate measurements — Rate measurements give an instantaneous indication of the intensity of a radioactive source or a radiation exposure field. (Such a measurement is similar to that made by the speedometer in a car which indicates the rate at which the car is moving.)

Integrated measurements — Integrated measurements give the amount of radiation exposure accumulated over a definite period of time. (An integrating instrument is analogous to the odometer in a car which tells how many kilometers or miles have been driven.)

Contamination measurements — Contamination measurements are made directly and indirectly. Generally, direct measurements on samples of snow, water, and so on must be made in a laboratory in order to obtain meaningful results, but direct measurements on surfaces can be made in the field using specially designed contamination meters. Indirect measurements are made to find out how easily surface contamination can be transferred. A piece of paper wiped over the contaminated surface is checked and if no radioactivity is detected on the piece of paper, it indicates that any contamination that may exist will not be removed easily.

3.3 Estimation of Radiation Doses

Radiation doses may be external or internal.

For estimating *external* dose, due to radiation sources outside the body, those at risk are provided with an integrating device or *dosimeter* that responds to the radiation energy deposited in it. The most commonly used dosimeters during the clean-up program were the "film badge" (the degree of darkening of the film on developing can be calibrated against known exposures), and the quartz fibre electroscope, which can be read directly by the person using it. The dosimeter should respond to the radiation of interest in a manner similar to that of human tissue, and the irradiation conditions should be reasonably uniform. Under ideal conditions, it is possible to obtain good results, but under field conditions, it is often difficult to obtain accuracies better than 50%.

An alternative to the integrating device is to take the exposure rate measured with a suitable radiation survey meter and multiply it by the length of time the person has been exposed at that rate. This technique is most useful in predicting the dose that may be received in the performance of a certain operation.

An *internal* dose cannot be measured directly. By measuring the rate of elimination from the body of the radionuclide of interest, and by having knowledge of the metabolism, and the radioactive characteristics of the particular radionuclide, it is possible to formulate a mathematical model of the radionuclide's behaviour inside the body, from which the internal dose can be calculated.

It is not always possible to make measurements on the people concerned; then it is necessary to make measure-

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ments on the radioactive material itself, from which, knowing the material and its solubility, the dose resulting from ingestion of an assumed quantity can be calculated.

3.4 Methods of Calculating Internal Doses

Small particles that are *swallowed* will follow one of two possible routes, as shown in Figure 29, depending upon whether the material is classed as transportable or non-transportable — terms used by ICRP to described the ease with which different materials can transfer across body membranes.

In simple terms, if the material is classed as non-transportable it will simply pass through the gastrointestinal tract and be excreted from the body. If it is classed as transportable, some fraction of it will transfer from the small intestine to the body fluids, whence it can be deposited in other organs of the body; the remaining fraction behaves as non-transportable material.

The radiation dose received by any of the body organs depends upon a number of factors: the fraction of the ingested radioactivity that reaches a particular organ, the effective half-life of the radioactivity in the organ (the "effective half-life" combines the effects of radioactive decay and biological clearance from the organ), the effective energy deposited in the organ as a result of the radioactivity, and the mass of the organ (14, 15, 16).

The organ that receives the highest fraction of its maximum permissible dose is called the critical organ for ingestion of a particular form of radioactivity. For many radionuclides, the critical organ is the lower large intestine for ingestion of both soluble and insoluble material.

The mathematical model for calculating the dose to parts of the gastrointestinal tract is different from that for the other organs mainly because of the short residence time in each section (17).

In contrast to the ingestion situation, particles *inhaled* by nose or mouth will follow paths outlined in Figure 30. Part of the material inhaled will be deposited in the respiratory tract and the remainder will be exhaled. The respiratory tract is divided into three regions, the nasopharynx (N-P), the tracheo-bronchial (T-B) and the pulmonary (P) regions. The division of the inhaled material between these three regions depends upon the size and mass of the particles; large particles will be deposited mainly in the N-P region and smaller particles mainly in the P and T-B regions. The material is either cleared from these three regions through the blood and thence to other organs in the body, or is expelled by muco-ciliary action to the gastrointestinal tract; the route taken and speed of clearance are determined largely by the solubility or transportability of the material. The dose to the various organs, including the respiratory tract, can be calculated if the time-integral of the radioactivity in the particular organ, the energy deposited, and the mass of the organ are all known. Generally, in cases of inhaled radioactivity, if the material is classed as insoluble, non-transportable and strongly retained, the critical organ is the respiratory tract; if the material is classed as soluble, transportable and minimally retained, the choice of critical organ is more varied than for the case of ingestion of the same material, and could include bone, liver, kidney, spleen, lower large intestine, and total body.

The mathematical model for calculating dose to the respiratory tract (18, 19) assumes biological decay of a dispersed source of dust particles, whereas the concern caused by Cosmos 954 is with single particles which are either present or not present in the respiratory tract. This difficulty has been overcome by assuming that an inhaled particle resides in a particular region of the respiratory tract for a period of time equal to the mean biological life.

4. Calculated Doses and Discussion of their Significance

The most important radionuclides found in association with radioactive debris are listed in Table 15 together with the calculated dose to the critical organs

TABLE 15

Calculated Internal Dose Resulting from Intake of One Microcurie

Radioisotope	*Dose to Lower Large Intestine for Unit Activity Ingested, mrem/μCi	**Dose to Nasopharynx Region for Unit Activity Inhaled mrem/μCi
Chromium-51	1.7	10
Manganese-54	22.8	171
Iron-59	50.0	310
Cobalt-58	29.5	215
Cobalt-60	77.3	534
Strontium-89	95.0	407
Strontium-90	36.9	817
Zirconium-95	41.6	385
Niobium-95	27.4	192
Ruthenium-103	24.1	199
Ruthenium-106	228.0	1,039
Cesium-137	59.8	304
Barium-140	52.6	1,023
Lanthanum-140	84.3	726
Cerium-141	29.1	133
Cerium-144	227.8	964
Tantalum-182	66.3	415
Uranium-234	84.4	36,390
Uranium-235	91.4	66,160
Plutonium-239	91.4	39,350

* Calculated according to model of Dolphin and Eves (17) using numbers given by ICRP (14,15,16).
**Calculated according to the model given by ICRP (18) modified as described in text, section 3.4 above.

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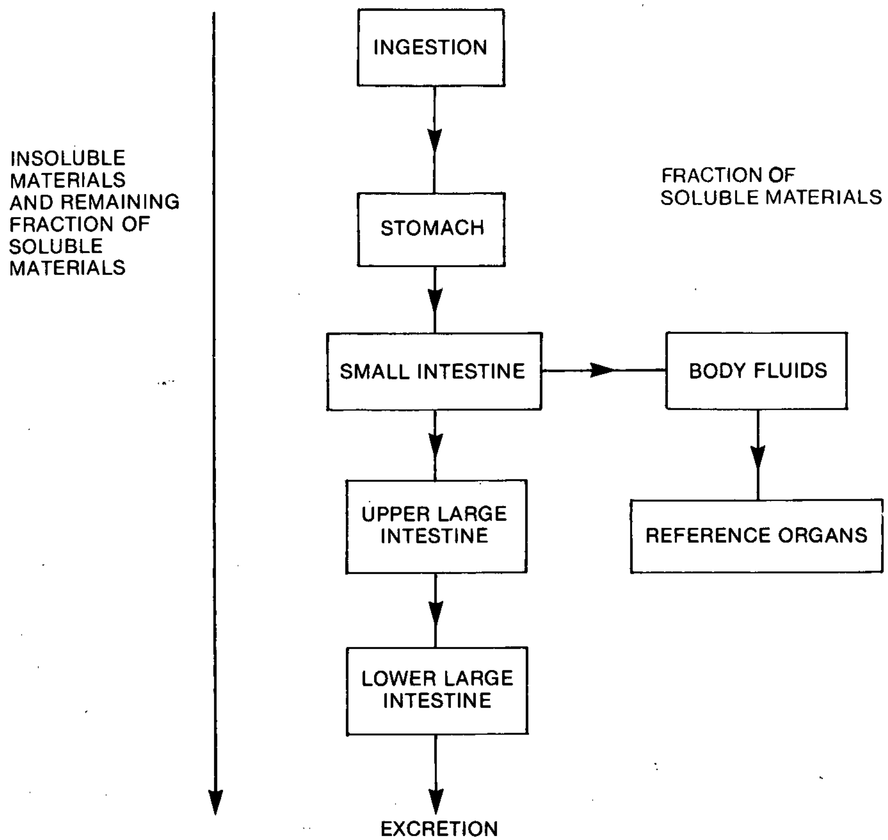

FIGURE 29. Simplified model of paths followed by ingested materials.

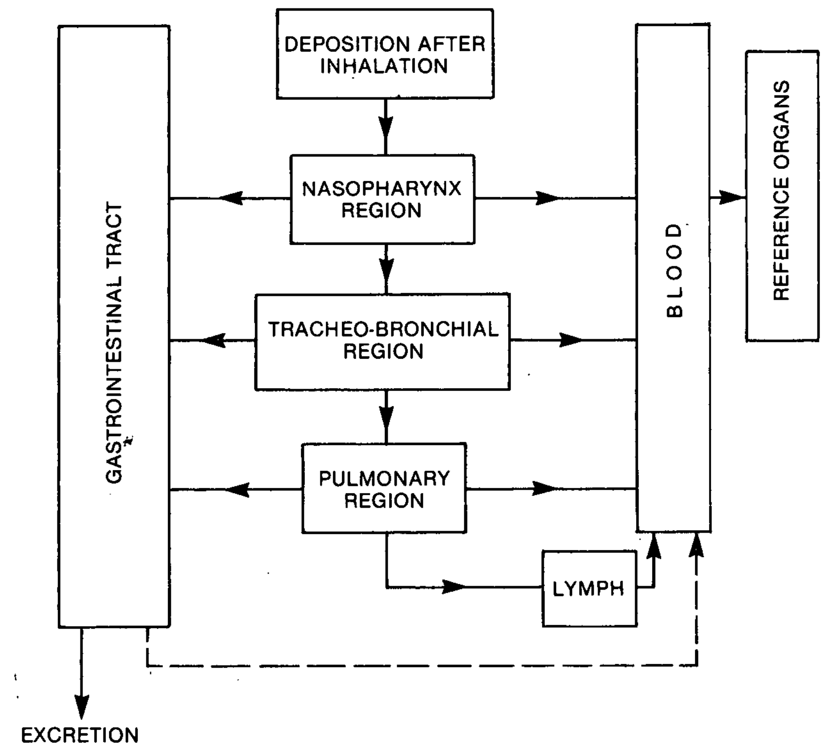

FIGURE 30. Simplified model of paths followed by inhaled materials.

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that would result from ingestion or inhalation of one microcurie.

In order to calculate the dose due to swallowing or breathing in a real particle, it is necessary to take account of the relative radioactivity of different radioisotopes. If this is done, it will be found that there was potential for high doses, near the time of impact, which could have been many times the maximum permissible dose for atomic radiation workers; this potential dose is reduced as the radioactivity decays with time.

These doses have been labelled as potential, because if a realistic mechanism of intake to the body does not exist there is little chance of actually receiving such doses. In the case of intake by ingestion, the generally low solubility limits the movement of the radioactivity in the environment and there is little likelihood of intake by the common routes in drinking water and food. In the case of inhalation, at the large size/weight end of the range of particles the potential dose is high, but the likelihood is very low of the particle becoming suspended in the air at breathing level and, with a high settling velocity, the chance of intake is also very low. As one approaches the lower end of the size/weight range, the chances of resuspension and intake increase, but the potential doses would be much smaller.

5. Non-radioactive Toxic Materials

In addition to the hazard of radiation, the presence of beryllium was of concern; beryllium is a highly toxic element, and extra care was needed both in the field and in laboratory operations to avoid contamination. A serious contamination of WNRE's hot cell facility (not of people) by dust from sawing a beryllium cylinder required painstaking clean-up.

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Appendix C

Portable Field Instruments

Table 16 summarizes the nature and application of the various portable field instruments employed at one time or another in the search and recovery operations.

Most instruments are designed for operation over a reasonable range of environmental conditions, but the extreme cold experienced in the Northwest Territories during the months of January, February and March posed a severe test of all instruments. All field instruments were of necessity powered by batteries. The extreme cold shortened battery-life in most cases to such an extent that it was essential to keep batteries warm by either holding the whole instrument inside one's parka between uses, or removing the batteries and keeping them in a warm pocket until required again — some instruments had the advantage of having a separate power supply unit which could be kept warm inside clothing while only the detector and meter needed to be exposed to the low temperatures. Since it was necessary to wear heavy mittens, any delicate adjustments of instruments were difficult out-of-doors.

During search operations, instruments with an audible output were useful since visual observations were often very difficult under the weather conditions existing.

Instruments with co-axial cables also presented a problem if the cable was permitted to get too cold, and the low humidity resulted in spurious readings due to static electricity.

TABLE 16

Principal Instruments Used in Field

Specific application	Name or type of instrument and model number	Detector*	Range of readout	Manufacturer or supplier
Search and recovery. Phase I only	Low range gamma survey meter. Model PRM-4	Scintillator 1" x 1" NaI cylinder	0–5,000 μR/h	Eberline
Search and recovery. Phases I and II	Low range gamma survey meter. Model PRM-7	Scintillator 1" x 1" NaI cylinder	0–5,000 μR/h	Eberline
Search and recovery. Phase I and II	Low range gamma survey meter. Model 19	Scintillator 1" x 1" NaI cylinder	0–5,000 μR/h	Ludlum
Search and recovery. Phases I and II	Model SPP 2NF scintillometer	Scintillator 1" x 1 1/2" NaI. Variable threshold	0–15,000 CPS	Saphymo-Stel
Search and recovery. Phase II only	Low range gamma survey meter. Model TC-33A	Scintillator 1 1/2" x 1 1/2" NaI cylinder	0–5,000 μR/h	McPhar
Field assessment of hazard. Phases I and II	Wide range beta/gamma survey. Model PIC-6	Ionization chamber with beta window.	0.2 mR/h - 1,000 R/h	Eberline
Field assessment of hazard. Phase I only	Gamma survey meter. Model 5016C	Two geigers	0.2 mR/h - 10R/h	Canadian-Admiral
Field assessment of hazard. Phases I and II	Beta/Gamma survey meter. Model LB-1200	Geiger with beta window.	1 μR/h - 100 mR/h	Berthold
Field assessment of hazard. Phases I and II	Teletector multi-range gamma survey meter. Model 6112	Geiger with telescopic probe	100 μR/h - 1,000 R/h	Eberline
Field assessment of hazard. Phases I and II	Contamination meter. Model E-140	Pancake geiger. Model HP-260 for surface contamination measurements. Model HP-210 with SH-4 shield for swipes and air filter counting		Eberline
Field assessment of hazard. Phases I and II	Mini-scaler Model PS-2-2	Pancake geiger Model HP-210 with SH-4 shield.		Eberline
Field assessment of hazard. Phases I and II	Personal air sampler. Model Siersat. Whatman 41 filter papers			Nuclear Associates

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Field assessment of hazard. Phases I and II	Alpha/gamma counter. Model PAC-1SAGA	Geiger for gamma 59 cm^2 ZnS sheet scintillator for alpha.	Gamma: 0-2 R/h Alpha: 0–2,000,000 CPM.	Eberline
Field assessment of hazard. Phase I only	Portable gamma spectrometers.	Scintillator, NaI Solid state, Ge-Li.		Supplied by US NEST
Field assessment of hazard. Phase II only	Pulse height analyser system. Model TN-1706	Scintillator. 2" x 2" NaI in 2" lead shield.		Tracer–Northern

*Dimension in inches are as given by supplier.

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Appendix D

TABLE 17

Summary of Fragments Recovered

Hit No. (Note 1)	Position (Note 2)	Date & Means of Discovery	Physical Description	Gamma Radiation Field* (Note 3)	Date of Recovery
ML-1(1)	WE 764 679	High altitude search 27/1/78	Charred metal piece approx. 225mm x 75mm x 6.5mm	Up to 200 R/h near contact	4/2/78
ML-2(1)	WE 948 803	MRS 5/2/78	Charred metal rod approx. 100mm long x 20 mm diam.	30 R/h contact 150 mR/h at 1 m	15/2/78
ML-5(1)	WE 746 717	Ground search 30/1/78	Rod similar to ML-2(1)	10 R/h near contact 150 mR/hr at 1 m	31/1/78
ML-6(1)	WE 959 809	High altitude search 30/1/78	Rod similar to ML-2(1)	25 R/h contact 100 mR/h at 1 m	10/2/78
ML-10(1)	WE 678 715	Visual from air 31/1/78	Hollow cylinder approx. 500mm long x 360mm diameter and 12 fragments various sizes	Not radioactive	31/1/78
ML-11(1)	WE 946 818	Ground search 1/2/78	Rod similar to ML-2(1)	2 R/h contact	2/2/78
ML-12(1)	XE 006 765	Helicopter search 2/2/78	Piece of ribbed sheathing, approx. 60mm long and 40mm wide	30 R/h contact	3/2/78
ML-13(1)	WE 816 740	MRS 5/2/78	Rod similar to ML-2(1)	100 mR/h at 1 m	20/2/78
ML-15(1)	WE 683 667	MRS 8/2/78	Rod similar to ML-2(1)	600 mR/h contact 10 mR/h at 1 m	4/3/78
ML-16(1)	WE 745 718	MRS 7/2/78	3 small flakes in cluster	100 mR/h at 1 m for the cluster	20/2/78
ML-19(1)	WE 874 766	MRS 5/2/78	Rod similar to ML-2(1)	10 R/h contact 125 mR/h at 1 m	26/2/78
ML-20(1)	WE 881 778	MRS 5/2/78	Rod similar to ML-2(1)	80 R/h contact 200 mR/h at 1 m	26/2/78
ML-22(1)	WE 503 539	MRS 16/2/78	Flake, black, size of a potato chip, approx 25mm long	10 R/h contact	18/2/78
ML-23(1)	WE 250 488	MRS 16/2/78	Rod similar to ML-2(1)	6 R/h contact 100 mR/h at 1 m	2/3/78
ML-24(1)	WE 183 424	MRS 16/2/78	Part of rod similar to ML-2(1) 50mm long	10 R/h contact	18/2/78
ML-32(1)	XE 033 849	Helicopter search 21/3/78	Rod similar to ML-2(1)		5/4/78
ML-33(1)	WE 495 585	Helicopter search 23/3/78	Metal fragment approx. 75mm x 25mm x 3mm	100 mR/h at 1 m	24/3/78
ML-35(1)	WE 900 784	Air search July 1978	Rod similar to ML-2(1)	2 R/h (and 4 rad/h) near contact; 100 mR/h at 30 cm	July 1978
ML-36(1)	WE 965 815	Air search July 1978	Rod similar to ML-2(1)	20 R/h (and 100 rad/h) near contact; 70 mR/h (and 100 mrad/h) at 1 m	July 1978 (Note 4)
ML-37(1)	WE 956 787	Air search August 1978	Rod similar to ML-2(1)	30 mR/h (and 100 mrad/h) at 1 m	August 1978
ML-38(1)	WE 968 791	Air search August 1978	Rod similar to ML-2(1)	9 R/h (and 10 rad/h) near contact; 70 mR/h (and 150 mrad/h) at 30 cm	August 1978
ML-39(1)	WE 904 845	Air search August 1978	Rod similar to ML-2(1)	20 R/h (and 20 rad/h) near contact; 500 mR/h (and 1.3 rad/h) at 30 cm	August 1978

*All readings are meter readings uncorrected for background.

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Summary of Fragments Recovered (cont'd)

Hit No. (Note 1)	Position (Note 2)	Date & Means of Discovery	Physical Description	Gamma Radiation Field* (Note 3)	Date of Recovery
ML-40(1)	WE 940 718	Air search August 1978	Small metallic flakes; 20 mm x 10 mm, and 10 mm x 5 mm		August 1978
ML-41(1)	WE 410 557	Air search August 1978	Rod similar to ML-2(1)	3-4 R/h near contact Small area also contaminated	August 1978
ML-2(2)	XE 154 906	MRS 5/2/78	Rod similar to ML-2(1)	40 R/h contact 50 mR/h at 1 m	28/2/78
ML-6(2)	XE 074 866	MRS 5/2/78	Rod similar to ML-2(1)	25 R/h contact 100 mR/h at 1 m	13/2/78
ML-6(2)B	XE 074 866	Helicopter search 5/4/78	Second rod similar to ML-2(1)	25 R/h contact 100 mR/h at 1 m	5/4/78
ML-7(2)	XE 049 861	MRS 5/2/78	Rod similar to ML-2(1)	50 R/h contact 100 mR/h at 1 m	13/2/78
ML-8(2)	XE 090 881	MRS 5/2/78	Rod similar to ML-2(1)	100 R/h contact 150 mR/h at 1 m	13/2/78
ML-9(2)	XE 028 845	MRS 5/2/78	Rod similar to ML-2(1)	20 R/h contact 125 mR/h at 1 m	2/3/78
ML-10(2)	XE 251 946	MRS 7/2/78	Rod similar to ML-2(1)	15 R/h contact 50 mR/h at 1 m	3/3/78
ML-11(2)	XE 300 975	MRS 7/2/78	Rod similar to ML-2(1)	12 R/h contact 170 mR/h at 1 m	3/3/78
ML-11(2)B	XE 300 975	Helicopter search 5/4/78	Small flakes		6/4/78
ML-12(2)	XE 100 885	MRS 7/2/78	Rod similar to ML-2(1)	10 R/h contact 80 mR/h at 1 m	6/3/78
ML-12(2)B	XE 100 885	Helicopter search 5/4/78	Second rod similar to ML-2(1)	10 R/h contact 80 mR/h at 1 m	6/4/78
ML-13(2)	XE 125 879	MRS 8/2/78	Rod similar to ML-2(1)	6 R/h contact	3/3/78
ML-14(2)	XE 131 884	MRS 8/2/78	Rod similar to ML-2(1)	60 R/h contact 150 mR/h at 1 m	4/3/78
ML-15(2)	XE 159 903	MRS 7/2/78	Rod similar to ML-2(1)	33 R/h contact 100 mR/h at 1 m	26/2/78
ML-16(2)	XE 206 936	MRS 7/2/78	Rod similar to ML-2(1)	60 R/h contact 80 mR/h at 1 m	28/2/78
ML-17(2)	XE 228 932	MRS 8/2/78	Rod similar to ML-2(1)	12 R/h contact 60 mR/h at 1 m	3/3/78
ML-18(2)	XE 219 912	MRS 8/2/78	Rod similar to ML-2(1)	7 R/h contact 150 mR/h at 1 m	5/3/78
ML-19(2)	XE 230 913	MRS 8/2/78	Rod similar to ML-2(1)	10 R/h contact 150 mR/h at 1 m	5/3/78
ML-20(2)	XE 318 961	MRS 8/2/78	Rod similar to ML-2(1)	12 R/h contact 70 mR/h at 1 m	5/3/78
ML-21(2)	XE 325 968	MRS 8/2/78	Rod similar to ML-2(1)	15 R/h contact 80 mR/h at 1 m	5/3/78
ML-23(2)	XE 354 974	MRS 10/2/78	Rod similar to ML-2(1)	6 R/h contact 30 mR/h at 1 m	5/3/78
ML-25(2)	CA 537 066	MRS 10/2/78	Flaky slice of cinderlike material approx. 30mm long	8 R/h contact 30 mR/h at 1 m	6/3/78

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Summary of Fragments Recovered (cont'd)

Hit No. (Note 1)	Position (Note 2)	Date & Means of Discovery	Physical Description	Gamma Radiation Field* (Note 3)	Date of Recovery
ML-26(2)	XF 493 115	MRS 10/2/78	Metal Cylinder 250mm long x 100mm diam.	10 R/h contact 80 mR/h at 1 m	12/3/78
ML-27(2)	CA 839 185	MRS 10/2/78	Horseshoe shaped metal piece 100mm across, 50mm thick	6 R/h contact 300 mR/h at 30cm	5/3/78
ML-28(2)	CA 911 261	MRS 10/2/78	Cylinder similar to ML-26(2)	15 R/h contact	17/3/78
ML-29(2)	CA 919 256	MRS 10/2/78	Cylinder similar to ML-26(2)	10 R/h contact 600 mR/h at 30cm	2/3/78
ML-30(2)	XE 333 960	Helicopter search 26/2/78	Particle	150 mR/h near contact	12/3/78
ML-32(2)	XE 335 965	MRS 6/3/78	Sliver about 10mm by 100mm	30 mR/h at 1 m	6/3/78
ML-33(2)	CA 854 238	Helicopter search 20/3/78	Cylinder similar to ML-26(2)		23/3/78
ML-34(2)	CA 865 245	Helicopter search 22/3/78	Cylinder similar to ML-26(2)		23/3/78
ML-35(2)	XE 128 874	Air search August 1978	Rod similar to ML-2(1)	8 R/h (and 15 rad/h) near contact; 100 mR/h (and 200 mrad/h) at 30 cm	August 1978
ML-1(3)	DA 054 304	MRS 10/2/78	Cylinder similar to ML-26(2)	10 R/h contact 400 mR/h on one end at 30 cm 800 mR/h on opposite end at 30 cm	5/3/78
ML-2(4)	EA 390 744	Visual from ground 28/1/78	Complex shaped object; concave thin plate or cracked cylinder end with tubular (double) braces and related parts	15 R/h contact	19/2/78
ML-1(9)	WE 030 110 Murky Lake area	Helicopter and ground search 22/2/78	6 particles	100–2000 mR/h contact	22/2/78
	WE 123 193 Snowdrift area	Helicopter and ground search 10/2/78	97 particles	5–1000 mR/h contact	14/2/78 to 21/2/78
ML-2(9)	WE 205 220	Helicopter search 12/2/78	Flake	40 mR/h contact	Not recovered (Note 5)
ML-3(10)	VE 675 155	MRS 20/2/78	Chunk of slag about 25mm x 15mm x 10mm	500 R/h contact	23/2/78
ML-5(10)	VE 762 261	MRS 1/3/78	Rod similar to ML-2(1)	10 R/h contact 200 mR/h at 1 m	5/3/78
ML-5(10)B	VE 762 265	MRS 1/3/78	Second rod similar to ML-2(1) & sliver of material		5/3/78
ML-6(10)	VE 716 218	MRS 2/3/78	End of rod approx. 20mm long	5 R/h contact 40 mR/h at 1 m	9/3/78
ML-7(10)	VE 845 225	MRS 2/3/78	Black chunk of material 25mm dia.	20 R/h contact 90 mR/h at 1 m	9/3/78
ML-8(10)	VE 937 249	MRS 2/3/78	Sliver about 80mm long x 3mm wide + small particle 3mm in diameter	25 R/h contact 110 mR/h at 1 m	9/3/78
ML-10(10)	VE 735 140	MRS 10/3/78	Irregular flake approx. 20mm x 15mm, + 6 particles	100 mR/h at 1 m	11/3/78
ML-11(10)	VE 650 137	MRS 10/3/78	Particles	10 mR/h at 1 m	11/3/78
ML-14(10)	VD 505 970	MRS 11/3/78	Small particle	10 mR/h at 1 m	19/3/78
ML-15(10)	VD 532 983	MRS 11/3/78	Small flake approx. 7mm long	20 mR/h at 1 m	19/3/78

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Summary of Fragments Recovered (cont'd)

Hit No. (Note 1)	Position (Note 2)	Date & Means of Discovery	Physical Description	Gamma Radiation Field* (Note 3)	Date of Recovery
ML-17(10)	VE 725 132	MRS 11/3/78	Small fragment approx. 10mm x 10mm x 5mm	40 mR/h at 1 m	21/3/78
ML-18(10)	VE 643 130	Helicopter 11/3/78	Specks in snow	40 mR/h at 1 m	11/3/78
ML-19(10)	VE 651 121	Helicopter 11/3/78	Specks in snow	40 mR/h at 1 m	11/3/78
ML-20(10)	VE 665 103	MRS 11/3/78	Sliver	40 mR/h at 1 m	19/3/78
ML-21(10)	VD 524 943	MRS 12/3/78	Long sliver	10 R/h at 50mm 105 mR/h at 1 m	16/3/78
ML-22(10)	VE 700 090	MRS 12/3/78	Particle Particle	8 mR/h at 1 m 4 mR/h at 1 m	19/3/78 24/3/78
ML-24(10)	VE 836 103	MRS 12/3/78	Flake approx. 15mm square	100 mR/h at 1 m	27/3/78
ML-25(10)	VE 657 105	Helicopter 14/3/78	Small triangular shaped flake	10 mR/h at 1 m	19/3/78
ML-27(10)	VE 685 110	Helicopter 17/3/78	Particle	8 mR/h at 1 m	24/3/78
ML-28(10)	VD 555 990	Helicopter 17/3/78	Small Flake	80 mR/h at 1 m	21/3/78
ML-32(10)	VE 905 256	Air search August 1978	Small metallic flake 20 mm x 5 mm	3 R/h near contact 20 mR/h at 1 m	August 1978
ML-1(11)	VD 270 997	MRS 7/3/78	50mm dia. x 3mm thick, black plate, not flaky	40 R/h contact 200 mR/h at 1 m	8/3/78
ML-3(11)	VD 396 953	MRS 12/3/78	Very small specks in snow	300 mR/h contact 2 mR/h at 1 m	16/3/78
ML-4(11)	UD 460 630	Helicopter 12/3/78	Flat oval plate 140mm x 90mm x 35mm	40 R/h contact 900 mR/h at 1 m	16/3/78
ML-5P(11)	UD 610 590	Ground search 14/3/78	19 particles		21/3/78
ML-6(11)	VD 349 827	MRS 14/3/78	Chip approx. 3mm square	10 R/h contact, 10 mR/h at 1 m	16/3/78
ML-6(11)B	VD 349 827	Helicopter 8/4/78	Specks in snow		8/4/78
ML-7(11)	VD 411 805	MRS 14/3/78	Chip approx. 10mm long	4 R/h near contact, 40 mR/h at 1 m	16/3/78
ML-7(11)B	VD 411 805	Helicopter 8/4/78	Speck in snow		8/4/78
ML-8(11)	UD 637 531	MRS 26/3/78	1 Particle	1 mR/h at 1 m	29/3/78
ML-8(11)B	UD 637 531	Helicopter 8/4/78	Speck in snow		8/4/78
ML-9(11)	UD 505 539	MRS 26/3/78	2 Particles	1 mR/h at 1 m	29/3/78
ML-10P(11)	VD 280 670 area Simpson Islands	Ground search 30/3/78	8 Particles		30/3/78
ML-1(12)	PU 125 170	MRS 31/3/78	Sheet metal approx. 220mm x 80mm x 3mm + 1 small particle		5/4/78
ML-1P(13)	NT 760 435	Ground search 27/2/78	2 particles	1 mR/h at 1 m	27/2/78
ML-2P(13)	UD 670 165 area Great Slave Lake	Ground search 13/3/78	19 particles		13/3/78
ML-3P(13)	NS 950 815 area Buffalo Lake	Ground search 19/3/78 and 22/3/78	19 particles	1-18 mR/h at 1 m	19/3/78 and 22/3/78
ML-4P(13)	NT 685 370 Hay River area	Ground search Feb.-Mar. 78	48 particles		Completed 9/3/78

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Summary of Fragments Recovered (cont'd)

Hit No. (Note 1)	Position (Note 2)	Date & Means of Discovery	Physical Description	Gamma Radiation Field* (Note 3)	Date of Recovery
ML-5P(13)	PT 380 465 Pine Point area	Ground search Feb.-Mar. 78	176 particles		Completed 5/3/78
ML-6P(13)	UC 565 857 area Fort Resolution	Ground search Feb. - Mar. 78	110 particles		Completed 1/3/78
ML-7P(13)	NS 715 330	Ground search 6/4/78	Speck in snow		6/4/78
ML-8P(13)	PU 100 000 area Great Slave Lake	Ground search 7/4/78	6 particles		7/4/78
ML-1P(14)	VC 540 250 area Tsu Lake	Ground search 23/3/78	Contaminated snow No particles found		
ML-2P(14)	WB 000 830 area Pilot Lake	Ground search 2/4/78	36 small particles		2/4/78
ML-3P(14)	WD 110 335 area Rutledge Lake	Ground search 5/4/78	7 small particles		5/4/78
ML-4P(14)	VD 070 070 Rocher River	Ground search 2/4/78	2 small particles		2/4/78

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Radioactive Particles Recovered During Summer 1978 (Note 6)

(with some examples of radioactivity level)

Position		Particles Recovered
HAY RIVER, NWT	— Community (average 19 μR/h at 1 meter, 80 mrad/h near contact)	119
	Adjacent highways	7
PINE POINT, NWT	— Community (average 24 μR/h at 1 meter, 90 mrad/h near contact)	422
	Adjacent highways	112
FORT RESOLUTION, NWT	— Community (average 22 μR/h at 1 meter, 140 mrad/h near contact)	494
	Adjacent highways	414
SNOWDRIFT, NWT	— Community (average 30 μR/h at 1 meter, 9 mrad/h near contact)	9
	Frontier Lodge	1
FORT SMITH, NWT	— Community (average 10 μR/h at 1 meter, 28 mrad/h near contact)	1,110
	Adjacent highways	230
SALT RIVER, NWT	— Community	11
BELL ROCK, NWT	— Community	65
CARLSON LANDING, ALTA	— Community	2
FORT FITZGERALD, ALTA	— Community	1
HAY CAMP, ALTA	— Community	2
PEACE POINT, ALTA	— Community	20
FORT CHIPEWYAN, ALTA	— Community (average < bkgd at 1 meter, 11 mrad/h near contact)	14
MACDONALD LAKE, NWT	— Camp sites (East end)	11
BUFFALO LAKE, NWT	— Camp sites	3
TALSTON RIVER, NWT	— Power dam site	6
TSU LAKE, NWT	— Camp sites	2
NAUTAWA LAKE, NWT	— Camp sites	2
PILOT LAKE, NWT	— Fishing lodges	10
CHAMPAGNE LAKE, NWT	— Camp sites	2
HOOK LAKE, NWT	— Camp sites	2
THUBUN LAKE, NWT	— Fishing lodge	1
JACKFISH LAKE, NWT	— Camp site	1
SCHAEFER LAKES, NWT	— Camp site	1
OULTON LAKE, NWT	— Camp site	1
Unnamed lakes and along rivers	— Camp sites	8
Railway Line — HAY RIVER to PINE POINT		51
	Total recovered during summer	3,134

Notes:

1. Sequential hit numbers missing from summary identified suspected hits which were later deleted for the following reasons:

a) Confirmed or probable natural radiation source	—	48
b) Confusion in location, or MRS error	—	11
c) Unable to confirm by later search	—	25
d) Review of spectrum indicated false hit	—	23
e) Search found natural, non-radioactive feature	—	3
		110

2. Position locations are from Ten Thousand Meter Universal Transverse Mercator Grid, Zones 75 and 85, Canadian Topographical Map Series 1:250,000.

3. Gamma Radiation Fields were measured in the field at the time the fragment was first located and identified by a ground search party. The "contact" measurements in many cases were made in contact with the covering snow which may have been several centimeters thick.

   Whenever the Gamma Radiation Field is left blank, it means that the information is not readily available; however, all of the fragments and particles recovered were radioactive with the single exception of Hit Number ML-10(1).

4. Hit Numbers ML-35(1) to ML-41(1), ML-35(2) and ML-32(10) were located and recovered by contract during the Phase II Program.

5. ML-2(9) was confirmed as a flake of material by ground observation, but was blown away by downwash from a helicopter and could not be relocated.

6. A total of 3,134 small radioactive particles were located and recovered by ground search parties employed by the Phase II contractor in checking communities, connecting roads and railways, commercial fishing lodges, trapping and fishing camp sites and other inhabited or travelled areas.

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Appendix E

Pick-up and Transportation of Recovered Material

For the safe conventional transportation of radioactive material great effort has been put into the development of suitable containers. A number of container models have been produced by Atomic Energy of Canada Radiochemical Company, and approved for use by AECB after testing to meet stringent conditions.

The provision of containers to meet the sudden needs of the Cosmos 954 clean-up operations rapidly depleted the stock on hand, forcing the manufacture of additional stock and the use of other containers under strict control. Containers used are listed in Table 18.

Lead-shielded containers permit safe storage and shipment of radioisotopes and other radioactive materials. When debris began to be recovered, there developed an immediate shortage of conventional containers, and a number of special safe substitutes were urgently constructed. The F112 and F113 models were excellent for field use, except for the small capacity of the lead insert.

A 9000-lb container (F233) was kept on hand in case a large piece of reactor core was discovered, but was not required.

Standard drums, pails and cans, often with garbage bag liners, were used for low activity material. These containers overcame the objection to some of the shielded containers — the small cavity — but introduced a hazard in contamination because of difficulties in closing gaskets in the field under winter conditions. Since recovered material almost invariably included snow or ice (in Phase I), thawing of this raised the possibility of leakage of contaminated water. If material could not be kept frozen in transport, the trick of placing the container in a larger one was often employed, and contamination of aircraft and other transport was successfully avoided.

Ingoing and outgoing shipments of containers were under continuous examination by health physics staff, verifying that no contamination existed.

Field and Shipping Operations

The procedure for recovery of debris, handling and shipment to Pinawa included several steps:

1. Following location of radioactive material in the field, the pick-up team was sent to the spot (by helicopter or other means) and proceeded to recover the material. This might require use of long-handled tongs and lead-lined containers in the snow. Health physics capability was always part of the pick-up team in order to monitor exposure and to prevent contamination.

TABLE 18

Types of Containers*

Type	Number Available	Cavity dia. & ht. (inches)	Amount of Shielding (inches of lead)	Wt. (lb.)	Comments
F233	1	13 x 20	7	9000	standby
F112	7	3 x 4	1	135	18"x20" drum
F113	12	3 x 4	2	210	18"x20" drum
F239	18	very small	1	45	5 gal. pail
FC1**	1	2 x 4 x 11 rect.	2+	500	For ML-1(1)
FC2**	1	22 dia. x 60 high	0-1	500	partial shielding
FC3***	1	6 x 12	1-2	450	
FC4***	1	6 x 12	1-2	450	18"x20" drum
FC6***	14	4 x 6	1 3/4	275	18"x20" drum
FC7***	6	5 x 11	1 1/4	275	18"x20" drum
46 gallon	200+	22 x 36	—	—	
25 gallon	200+	18 x 29	—	—	
18 gallon	—	—	—	—	garbage pail
5 gallon	30	10 x 15	—	—	
1 gallon	100+	6 x 8	—	—	not used as outers

* Dimensions in inches for consistency with suppliers' standards
** Made in Alberta to meet needs of the program
***Made in Ottawa to meet needs of the program

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2. Material was brought first to Yellowknife, then sent to Canadian Forces Base (CFB) at Namao. Here space was made available by DND for samples to be held, repacked if necessary, given preliminary examination, and then shipped under escort to CFB: Winnipeg.
3. At CFB: Winnipeg a representative of WNRE at Pinawa met the plane with a truck and material was transported to Pinawa.

A travelling form accompanied each sample throughout its journey, and at each point of arrest or transshipment it was signed by the receiving person. For legal purposes, since each sample was considered a piece of evidence for anticipated dealings with the USSR, this procedure was followed consistently (Figure 31).

All but one shipment to Winnipeg were made in CF aircraft. The first shipment of debris went by common carrier, with all requirements of safety being met and with no risk to passengers, as a matter of expediency.

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ATOMIC ENERGY CONTROL BOARD

OPERATION MORNING LIGHT

SAMPLE TRANSMITTAL SHEET.

TO BE FILLED IN BY ORIGINATOR

Container Tag No. XC141 Date 19 Mar 78

UTM Grid Co-ordinates ML 14(10) VD 505-970

Sample: Field Identification ____ (use reverse side if necessary)

Originated by ____ Location ____

TO BE FILLED IN EACH TIME POSSESSION IS TRANSFERRED

(1) This sheet is to accompany sample at all times.
(2) All transfers are to be recorded and singed by individuals concerned.
(3) Any change to the sample should be noted and accounted for.
(4) All information derived for each sample should accompany this sheet.
(5) Sample should be stored only in secure (locked) place.

Date	Transferred From	Transferred to	Purpose, Actions Performed & Notes
19 Mar 78	1 sample	800 mR/hr @ 2"	
		15 mR/hr @ 1 meter } for the above	
	Note. Plastic bag not marked with small pcs of FP		
[illegible]			
21 Mar 78	[illegible]	W R Taylor	Storage at ED
22 Mar 78	W R Taylor	Michael [illegible]	Storage at ED
30 MAR 78	Michael [illegible]	[illegible]	Escort to Winnipeg
30 MAR 78	[illegible]	VB [illegible]	[illegible] CFB Wpg
MAR 3 1 1978	[illegible]	[illegible]	to [illegible]
[illegible] 31/78	[illegible]	R W Pollock	Send to WNRE Bunker.

FIGURE 31 Example of "sample transmittal sheet" that accompanied all recovered debris from first recovery to final storage at WNRE.

FOR USE BY OPERATION HQ CFB NAMAO ONLY:

Packaging ID F-239-7

HIT NUMBER ML 14(10)

Dose Rate (Packaged) mR/hr Date: 22.3.78

	Contact	1 meter
SIDE	2	0.004
TOP	0.15	0.006

R-1 Mar.2, 1978.

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Appendix F

Records of Exposure to Radiation of Search and Other Personnel

Records were kept for all personnel in any position to be exposed to radiation. Personal dosimeters were issued to those directly involved in search and recovery operations, and to all those handling or examining debris under laboratory conditions. Also, a limited number of warning dosimeters were made available to members of the public, particularly local inhabitants, who needed to enter areas where they might encounter radioactive material from the satellite. The dosimeters employed were of three sorts:

a) *Film dosimeters.* The Canadian search personnel wore film dosimeters supplied by the Radiation Protection Bureau of Nation Health and Welfare (RPB), which processed the films after each wearing period and issued dose reports. The US staff used their own regular dosimeters.

b) *Direct reading dosimeters.* Search teams and those involved in shipping the recovered items also wore a direct reading dosimeter (DRD), usually a quartz fibre electroscope, which permitted them to keep track of day-to-day exposures and also provided a backup for the film dosimeter.

c) *Warning dosimeters.* Warning dosimeters give a digital display of the accumulated exposure in milliroentgens and also produce an audible signal or "beep" at a rate depending upon the radiation intensity. A sharp increase in the beep rate gives warning of a radioactive fragment in the vicinity. These dosimeters were made available to members of the public, through the co-operation of the local RCMP detachments, along with simple instructions on how to use them and the action to take if the beep rate increased significantly.

Whole Body Dose Records

A summary of the whole body dose data for the operations is given in Table 19. Generally, the doses are based on film dosimeter measurements, but in the case of U.S. staff (which are included) the doses are based on DRD measurements.

The 302 people who wore dosimeters during Phase I field search were personnel from the Atomic Energy Control Board, Atomic Energy of Canada Limited, the Department of Energy, Mines and Resources, the Department of National Defence, Environment Canada, and the US Nuclear Emergency Search Team (NEST). The 21 who wore dosimeters during Phase II field search were mostly staff of the Canadian consultant who performed this work under contract to the Federal Government, together with a few members of the AECB staff.

TABLE 19

Whole Body Dose Summary

Type of Work	No. of people issued with dosimeters	No. of people who received a dose	Collective whole body, dose, man-rem.
Field search — Phase I	302	106	6.30
Field search — Phase II	21	6	0.31
Laboratory Analysis	35	35	2.00
Overall programme	353	145	8.61

* Note that while the collective whole body dose is additive in this table, the numbers of people involved are not; this is because a few people were involved in both phases of the field search.

The doses received while performing the laboratory analyses represent exposure at the Whiteshell Nuclear Research Establishment of AECL.

The distribution of doses received during Phases I and II field search is given in Figure 32; only those who received a measurable dose, i.e. 110 people, are included in this distribution. Of these, two received a measurable dose in both phases.

Other Dosimetry

In addition to measurement of the whole body dose, usually due to external gamma radiation, film dosimeters are capable of measuring the skin dose resulting from low penetration radiation. During Phase I, all field staff wore heavy arctic clothing which provided good protection for the skin against low penetration radiation, so that skin doses during this phase have been taken to be numerically equal to the whole body dose for each individual. Lighter clothing was worn during Phase II and skin dose as measured by film dosimeters was recorded for this period; of the 6 people who received a measurable dose during Phase II, only 3 received skin doses that exceeded the whole body dose. The highest recorded skin dose was 400 mrem during Phase II and 470 mrem during Phase I.

Urine samples were submitted by the field search teams for analysis of tritium and mixed fission products by RPB; no evidence was found of internal contamination.

Comments

A total of 353 people wore personal dosimeters at one time or another during the operations (see Table 19). Of

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these, 145 received a measurable dose (≥10 mrem) to the whole body. The collective whole body dose for the whole operation was 8.61 man-rem. The highest individual accumulated whole body dose was 470 mrem which is also the highest recorded individual skin dose; both of these doses are well below the maximum permissible doses for atomic radiation workers, i.e. 5,000 mrem per year for whole body exposures and 30,000 mrem per year for skin exposures.

The highest individual dose as well as the highest collective dose occurred during Phase I which corresponds to the period when most radioactive fragments were being recovered and the largest number of people were employed.

There was no evidence of internal contamination during the whole period.

Members of the public who used warning dosimeters did not receive any dose above natural background.

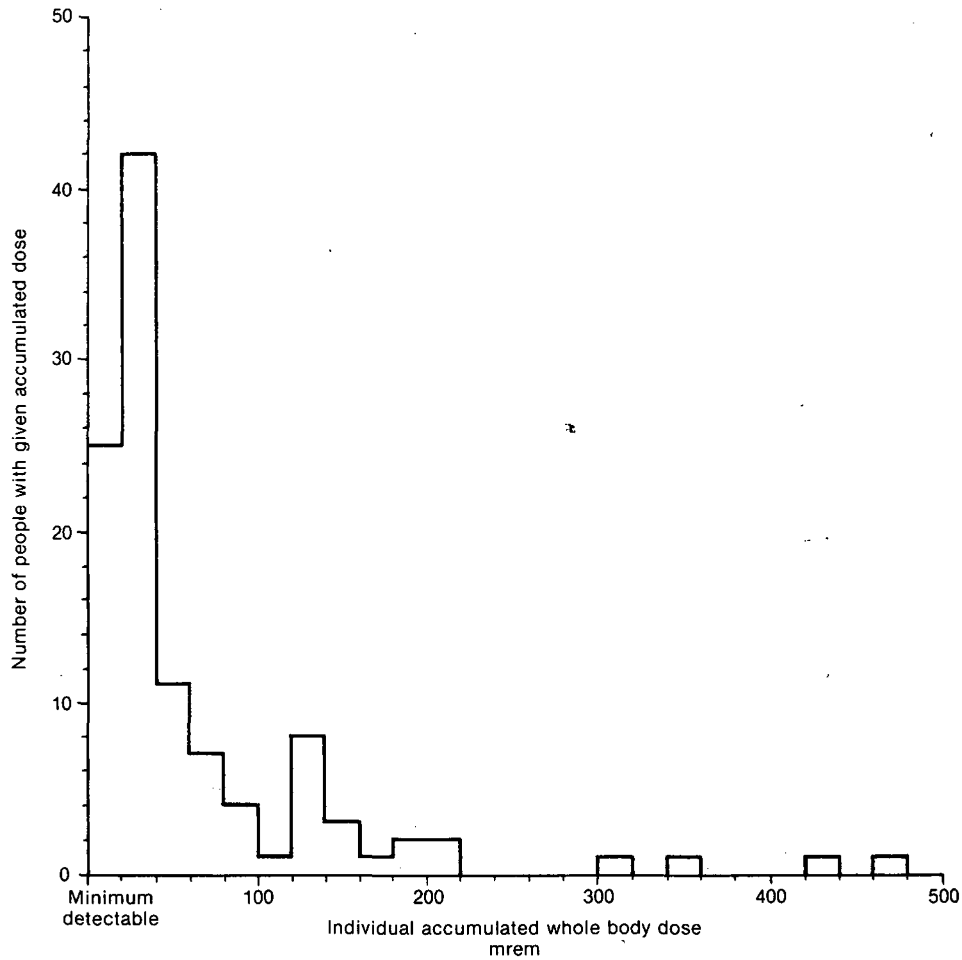

FIGURE 32 Distribution of individual doses received during Phases I and II of the field search and recovery operations.

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Appendix G

International Aspects

The Cosmos 954 episode was Canadian in the sense that it fell within Canadian borders, but a number of international aspects immediately became apparent.

1. The first one is obviously that the US had advance knowledge of the coming re-entry and, when this occurred, was best able to calculate the landing trajectory. In the circumstances, Canada was dependent upon this ability. Furthermore, the US possessed a forewarned Task Force with experience in location and clean-up of nuclear material. Thus, most operations in Phase I were joint in the sense that Canadian and US forces were both involved, the US team officially assisting the Canadians.
2. From the start, it was recognized that technical data arising from study and analysis of recovered debris might be of interest to other nations, but it was also clearly stated that these data would be the property of Canada. This was because in any eventual claim against the USSR, Canada would be the claimant. Data were made available to the US team in order to assist in refining ballistic studies that were concerned with the zone of fall of fragments of the satellite, but the interpretation of data from the health and safety viewpoints was a Canadian responsibility.
3. Finally, there was naturally much sudden interest on the part of other countries in the techniques employed in the Phase I and II operations for location and removal of debris. Cosmos 954 introduced to the world the spectre of unplanned re-entry of nuclear material, and others wish to profit by the experience gained in this event. Thus there have been several contacts with other governments, both directly by the AECB and through the Department of External Affairs. The publication by the Geological Survey of Canada of several papers on air-borne search techniques has provided answers to the most obvious questions raised by others. The following APPENDIX (H) summarizes the obvious lessons learned from this event.

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Appendix H

Lessons Learned from COSMOS 954 Re-entry

The re-entry of Cosmos 954 over the Northwest Territories of Canada on 24 January, 1978 offers an example of the problems presented to a country by such an event.

Earth-orbiting satellites will always re-enter at a low angle, and if burn-up is incomplete debris may be scattered over a distance of several hundred kilometres. If finely divided material is produced, it will be affected by the weather conditions existing at the time, chiefly by wind which may distribute such material over very large areas.

The major requirements posed by the event were:

1) Knowledge of the trajectory of the satellite on and following re-entry;
2) the capability of moving men and material across areas of the northern terrain under mid-winter conditions, and of setting up base camps for remote operations;
3) a means of surveying a vast and rather ill-defined area using air-borne radiation detection equipment, flying at controlled speeds and elevations, precisely locating detected items for subsequent recovery, and landing at will for material identification and recovery;
4) a means of safely recovering fragments and transporting them to a central handling and storage facility, preventing the exposure of search personnel, carriers, representatives of the press, and general public.

To meet these requirements required assistance from NORAD and U.S. expertise for the trajectory, and involved coordinated efforts from three main agencies, one responsible for operations and logistics, one with airborne detection experience, and one responsible for health and safety aspects of radioactive contamination.

With respect to what countries can do to prepare for such an eventuality, it is not likely that many will be able to afford to maintain on stand-by basis the full complement of personnel, equipment and instruments necessary to carry out a search and recovery operation of this sort. A few countries, notably USA and probably USSR, UK and France, do maintain resources for response to nuclear accidents. Certainly no single Canadian agency had available "on the shelf" the instrumentation needed, nor the complement of trained personnel to use it. As a result of this experience, however, the Canadian capability has now been greatly improved. To obtain the personnel needed meant the disruption of regular work programs, and although all agencies responded readily, the cost of this interference is a feature that should be recognized.

The Cosmos 954 episode now offers some experience but of course it is not all applicable elsewhere. It relates to subarctic winter conditions, it relates to a sparsely populated area, it relates to a particular type of terrain, and so on. The obvious aspects are the following:

1) Countries lying beneath the orbit of a failing satellite should be advised of estimated re-entry as far in advance as possible.
2) Without information on the major parameters of a nuclear-powered satellite's source — size, power, fuel type, degree and type of protection, etc. — a search will be hampered by uncertainty.
3) Policy on release of information should be clarified and explained publicly at the start of operations. It would be desirable for contiguous countries to seek a common position on public release of information.
4) A single coordinator for overall operations is essential.
5) Central control of communications for both search and recovery operations, and for public relations is necessary. Support capability should include printing, photography, telex, recording, radio and telephone.
6) Access to appropriate radiation detection equipment, or knowledge of a source of supply, is important.
7) Under the northern winter conditions that existed during Phase I of the Cosmos 954 operations, precise location of debris based on airborne survey requires a system of ground-positioned navigation beacons.
8) Containers suitable for transport, and a safe location for storage (interim or long term) of recovered material, are necessary.
9) It is essential to ensure means for quick analysis of debris, particularly with respect to the solubility of fragments small enough to be ingested or inhaled, and to identify the soluble components and their potential hazards to health. Determination of shape and mass parameters (as well as meteorological conditions at the time) will also be important in developing knowledge of airborne distribution of tiny particles. Analysis of drinking water supplies that may be contaminated by soluble debris should be begun without delay.
10) If there is any likelihood of legal follow-up or international litigation, a system for documentation and maintaining full records of debris recovery, at "rules of evidence" level, may be necessary. Costs of the operation must also be

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accounted in a standardized fashion by all participating agencies, in order to permit prompt preparation of eventual financial claims.

It might be suggested that the UN Committee on Peaceful Uses of Outer Space (UNCOPUOS) could refer the problem of search, recovery and clean-up to an appropriate health group such as WHO since the problem is essentially one of health physics as opposed to science and technology. The U.N. Disaster Organization is another possibility. Such an organization could explore the feasibility and desirability of collecting together a central pool of equipment as a long term project. In the short term, the group could document resources already existing in certain countries willing to make those resources available. A mechanism for requesting and organizing the use of such resources would also be required. At time of writing, there is an ongoing activity in UNCOPUOS, Canada participating, to investigate such possible actions.

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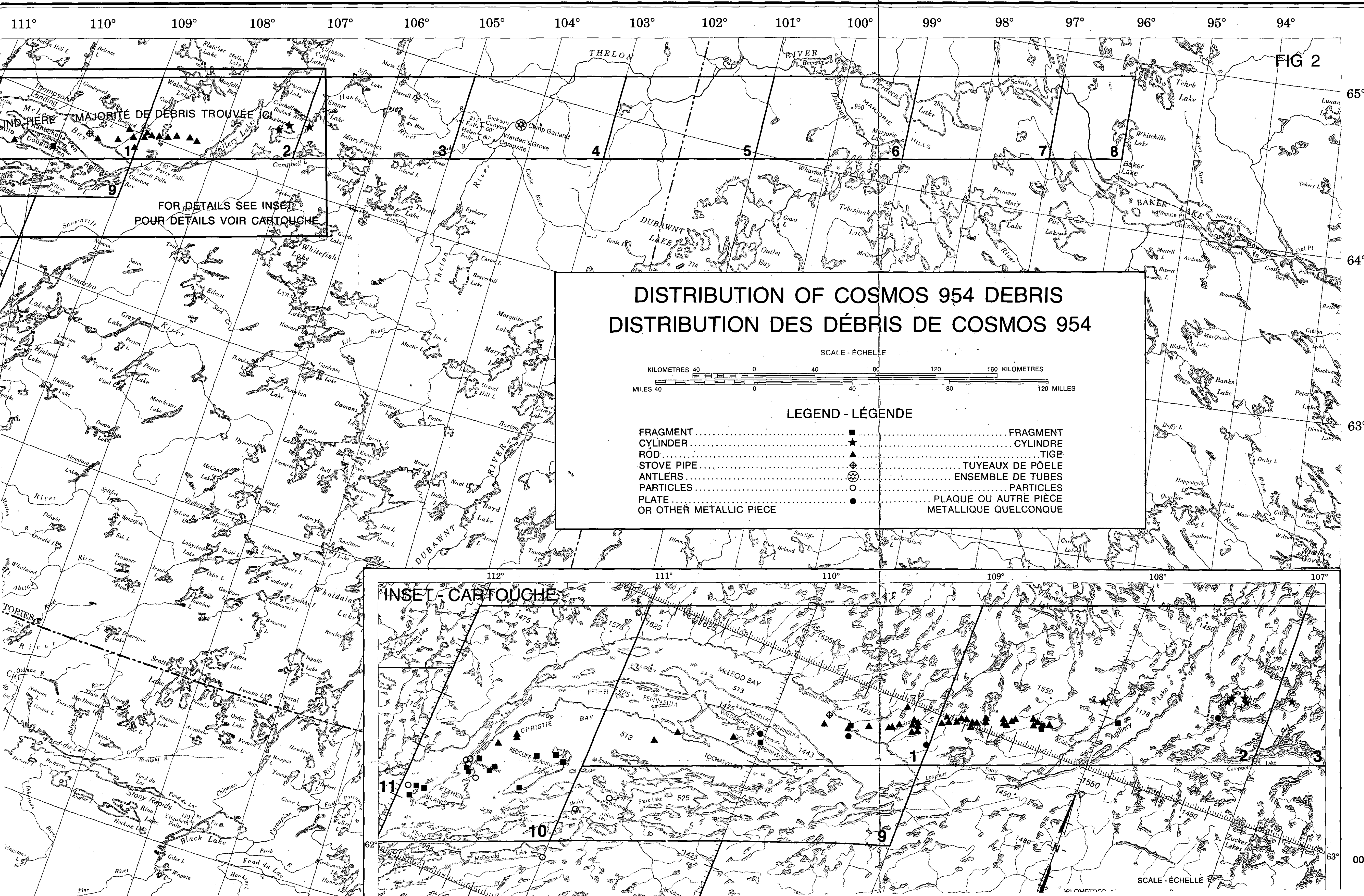

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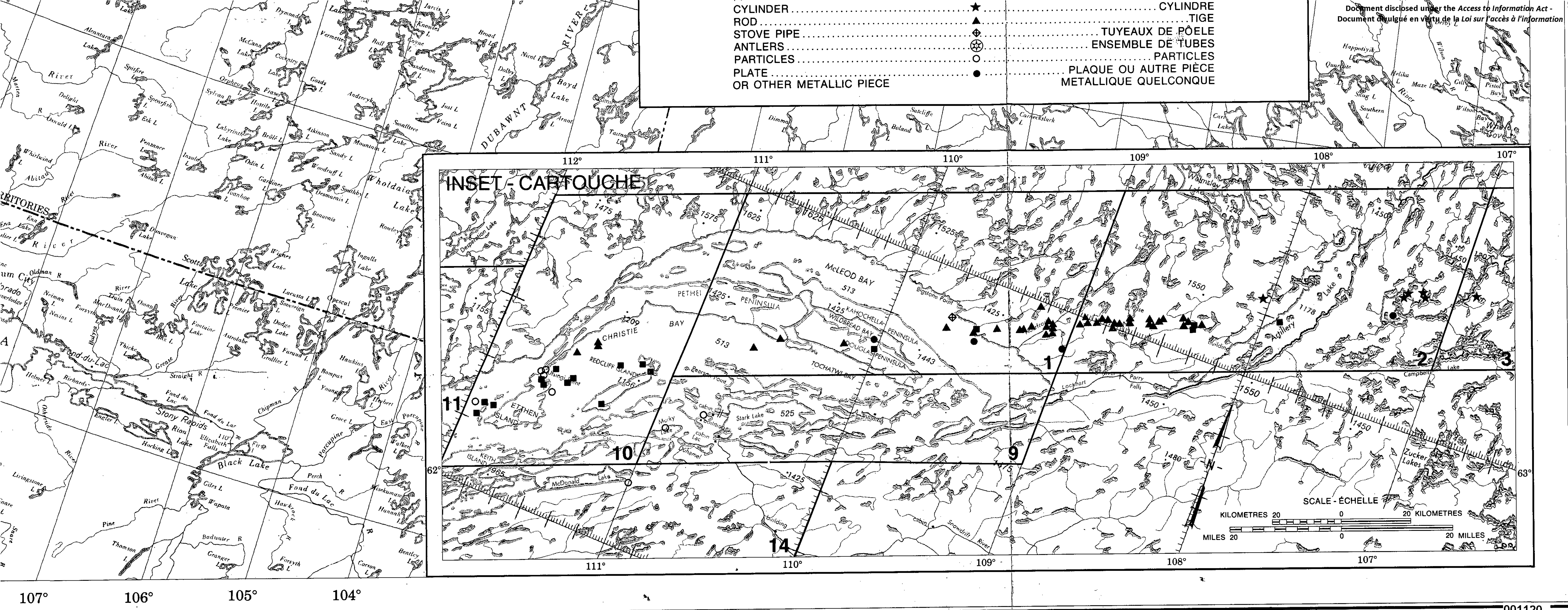

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ÉTABLIE POUR LA COMMISSION DE CONTRÔLE DE L'ÉNERGIE ATOMIQUE PAR LA DIRECTION DES LEVÉS ET DE
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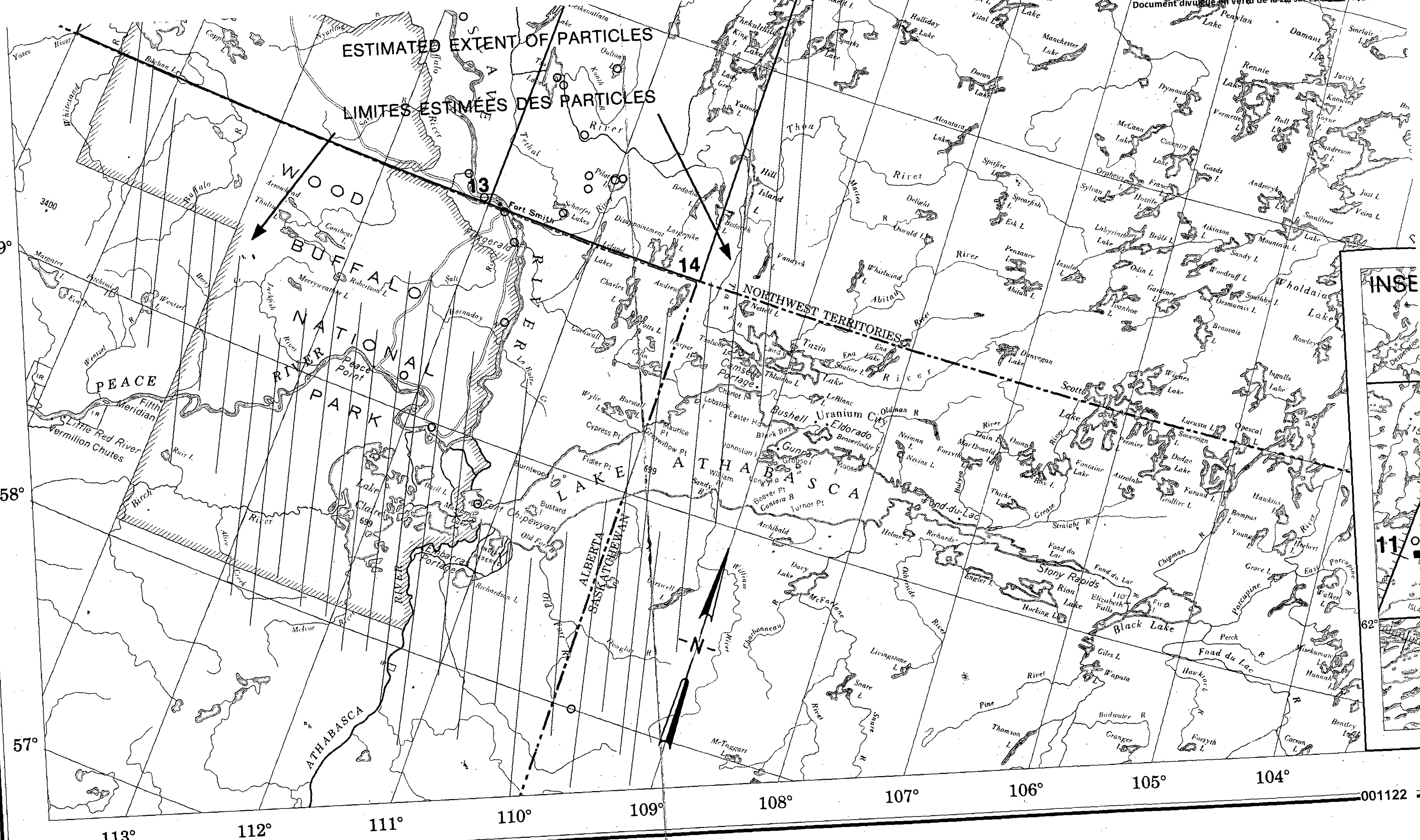
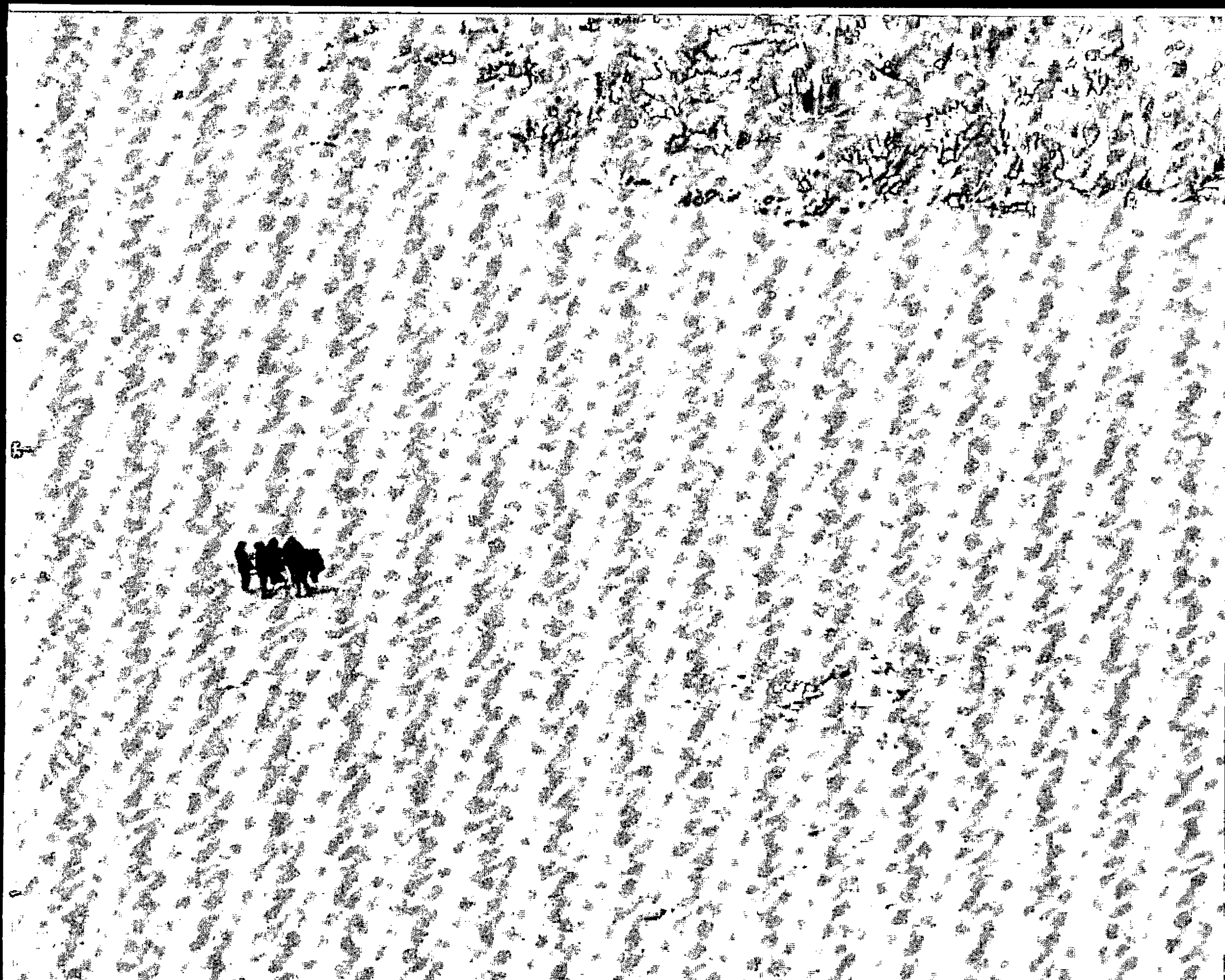


SURVEYS AND MAPPING BRANCH,

COSMOS 954

THE OCCURRENCE AND NATURE OF RECOVERED DEBRIS



Atomic Energy Control Board
Commission de contrôle de l'énergie atomique

001123

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COVER

The cover photograph shows the location of the assemblage of rods, later dubbed the "antlers", encountered on the Thelon River by members of a group of six men who were camping for the winter at Warden's Grove. This location is approximately 500 km north-easterly from Yellowknife, and represents the farthest east identification of Cosmos 954 debris. The photograph shows the obvious crater where the antlers were found; this crater is not an impact phenomenon but represents melting of the surface snow and ice by the heat of reaction of lithium hydride (which filled the control tubes) with melted snow. One can see the effects of spatter from the "crater" for some distance on all sides, and an elongated stain on the snow.

The photograph also shows the general nature of the land at the time when Cosmos 954 re-entered. Where there are trees, or scrub brush as in this picture, some topographical expression is visible, but otherwise land and water appear much the same, exhibiting only a wind-textured hard surface.

The area lies partly in Canada's zone of discontinuous permafrost (mean air temperature between -4°C and -8°C). It also overlaps the open woodland zone and the more northern forest-tundra zone. The environment of the area may be categorized as subarctic/boreal. Whatever the names and technical terms, the search area in winter is a most inhospitable place. With few exceptions such as in fast running rivers, all water is covered with ice feet thick, all ice and land is covered with snow which although not reaching the depths recorded in higher precipitation areas to the south nevertheless blankets everything and disguises or masks most summertime landmarks, and over all a piercing wind may blow, introducing a chill factor that may make the equivalent temperature as low as -100°C. Under these conditions mechanical equipment does not always function. At this particular spot, the first technical search group was forced to spend a night under survival conditions when their helicopter failed to start.

In winter, the land is stark, or starkly beautiful, depending on viewpoint, and it offers a real challenge to people from farther south. In the summer wild rivers and abundant lakes present another challenge that is being more and more taken up by those interested in getting back to nature, or in following the incredible footsteps of early explorers of the north. The summer growing period however, is squeezed into a period of about half that of the Toronto latitude. Flora and fauna must be tough to survive; their ecological equilibrium tends however to be susceptible to outside influences and slow to recover.

This was the locale of the Cosmos 954 search and recovery operations.

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H Q485-38

COSMOS 954

The Occurrence and Nature

of

Recovered Debris

by
W.K. Gummer,
F.R. Campbell,
G.B. Knight,
J.L. Ricard

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Summary

The Russian nuclear-powered satellite, Cosmos 954, re-entered the earth's atmosphere early on 24 January, 1978, watched first by the tracking instruments of NORAD and then by the startled eyes of a few residents of the Northwest Territories. Concern about radioactive debris, whose presence was quickly verified on the frozen surfaces of lakes and land, led to a massive airborne and ground search and recovery program that lasted from re-entry date to the middle of October, 1978, interrupted only by the spring break-up period. The search area extended from Great Slave Lake northeastward towards Baker Lake.

Only about 65 kilograms of material were found, although it is probable that the satellite weighed several tons. All fragments but one — itself weighing over 18 kg — were radioactive; many showed clear evidence of melting and erosion. A few were extremely radioactive and could under certain conditions have caused serious effects on people, even death. In addition to the obvious fragments that fell along a well-defined track nearly 600 km in length, a wide area stretching southwards from Great Slave Lake was affected by a scattered shower of minute particles representing the enriched fuel of the satellite's power source, with a highly variable density perhaps averaging a few hundred per square kilometre. Because of their radioactivity and of public concern about the hazards that might be presented by contamination of water supplies, or by pick-up of particles by clothing, for example, intensive searches were carried out in the Territories and adjacent Alberta and Saskatchewan, in frequented areas such as towns, roads, fishing and hunting camps in an effort to find and remove as much as possible of such material.

Laboratory studies were carried out on particles to learn their chemical and physical nature, in order to understand their probable behaviour in the general environment.

Search and recovery continued until it could be concluded that 1) it was most unlikely that highly radioactive fragments had been missed; 2) all obvious large fragments had been located and removed; 3) the risk to people from particles remaining in unfrequented areas was not great because of the particles' tiny size, their general insolubility, and their scattered distribution. Residual radiological risks were also fading rapidly relative to the natural radiation background.

Sommaire

La rentrée spectaculaire dans l'atmosphère du satellite nucléaire soviétique Cosmos 954, au-dessus des Territoires du Nord-Ouest, tôt le matin du 24 janvier 1978, a été vue par quelques-uns des habitants après avoir été repérée d'abord par les systèmes de NORAD. D'importants travaux de dépistage et de recouvrement des débris radioactifs furent entrepris dès que leur présence au sol fut déterminée. Ces travaux se sont poursuivis jusqu'au dégel du printemps et par après, jusqu'à la mi-octobre à partir du Grand Lac des Esclaves et dans une direction nord-est vers le lac Baker.

Même si le poids du satellite était probablement de plusieurs tonnes, seulement 65 kilogrammes environ de matériel furent récupérés. Sauf pour une pièce pesant 18 kilogrammes, tous les fragments récupérés étaient radioactifs; plusieurs avaient dû fondre et étaient corrodés. Les plus fortement radioactifs présentaient un danger pour la santé des personnes et dans certaines circonstances, même la mort. En plus des fragments récupérés dans le couloir de rentrée du satellite, long de quelques 600 kilomètres, des milliers de petites particules provenant du combustible enrichi du réacteur, furent dispersées sur une grande surface au sud du Grand Lac des Esclaves. La distribution de ces particules variait considérablement mais en moyenne elle était de quelques centaines par kilomètre carré. Vu les risques de contamination de l'eau d'approvisionnements et d'irradiation externe par des particules radioactives logées dans les vêtements, des recherches intensives furent menées dans les villes, sur les routes et autres endroits fréquentés tels les camps de pêche et de chasse situées dans les Territoires du Nord-Ouest et les provinces avoisinantes de l'Alberta et la Saskatchewan, dans le but d'en récupérer le plus grand nombre.

Les particules récupérées ont été étudiées en laboratoire pour établir leurs propriétés physiques et chimiques et en déterminer les effets possibles sur l'environnement.

Le dépistage et le recouvrement furent poursuivis jusqu'à ce que les autorités soient satisfaites d'avoir repéré et recouvré tous les fragments de taille importante et ceux qui étaient hautement radioactifs. Il était alors possible de conclure que le risque pour les personnes dans les régions peu fréquentées n'était pas grand en raison de la petite taille des particules, de leur insolubilité et de leur faible concentration. Étant donné que la radioactivité décroit avec le temps, son niveau se rapproche rapidement du niveau de la radioactivité naturelle.

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List of Abbreviations and Acronyms

AECB	Atomic Energy Control Board
AECL	Atomic Energy of Canada Limited
CWS	Canadian Wildlife Service
DFE	Dept. of Fisheries and the Environment
DND	Dept. of National Defence
EA	Dept. of External Affairs
EMR	Dept. of Energy, Mines and Resources
GSC	Geological Survey of Canada
ICRP	International Commission on Radiological Protection
INA	Dept. of Indian and Northern Affairs
NAST	Nuclear Accident Support Teams (DND)
NEST	Nuclear Emergency Search Team (USA)
NHW	Dept. of National Health and Welfare
NORAD	North American Air Defence
NRC	National Research Council
NWT	Northwest Territories
RCMP	Royal Canadian Mounted Police
RPB	Radiation Protection Bureau
USSR	Union of Soviet Socialist Republics
WNRE	Whiteshell Nuclear Research Establishment

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Figures 6,7,8,10,12,13,15,16,17,20,21,22,23,24 — Whiteshell Nuclear Research Establishment

Figures 9,11,14,15,18 and Cover — EG and G Incorporated

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COSMOS 954

The Occurrence and Nature of Recovered Debris

1. Introduction

Cosmos 954, a Russian nuclear-powered satellite, re-entered the earth's atmosphere early in the morning of 24 January, 1978. Telescopic camera reports from Hawaii indicated that the satellite, glowing from the friction of re-entry, and breaking up, was headed towards northern Canada over the Queen Charlotte Islands. Shortly thereafter, visual sightings in the Yellowknife area, Northwest Territories (NWT), confirmed that an unknown quantity of debris continued towards the ground in a northeasterly direction.

Cosmos 954 was placed in orbit in September 1977; it showed abnormal behaviour within weeks of its launching and its eventual re-entry was anticipated within the next few months. Actual date of re-entry was however uncertain, and it was not until early January, 1978 that this was foreseen to occur within the month. The American government notified all nations potentially affected on 19 January. On 20 January, the Canadian Department of National Defence (DND) warned all regional commanders and Nuclear Accident Support Teams (NAST) across Canada of the imminent re-entry, possibly over Canadian territory. On 23 January, several departments whose responsibilities might be touched upon by re-entry and landing were advised of the situation. Thus for many of those who became involved the advance notice was less than twenty-four hours; for some the information arrived after the event.

The known presence of a nuclear reactor on the satellite immediately raised concern about the nature of debris that survived to reach the earth's surface. The USSR had stated that Cosmos 954 was designed to burn up and disintegrate on re-entry, but in view of the telescopic and visual evidence of "landing" a search operation was at once instituted and as radioactive material began to be located a field program got underway that was to extend, with a pause during spring break-up, until mid-October, 1978.

Many problems were posed by the descent of Cosmos 954. There are towns along the south side of Great Slave Lake, but much of the area identified for search is uninhabited, and although this was an advantage in the sense that there were relatively small numbers of people endangered in that part of the area it was a disadvantage from the viewpoint of communications and access. Much of the search area lay in tundra and barrens, north of the treeline, and, under winter conditions, obvious landmarks such as rivers tend to be masked by snow and ice. Temperatures reach -40°C or lower, and with the wind chill factor perhaps as low as -100°C. Much of the area is utilized at one time or another of the year by native people and by other hunters and fishermen. Caribou herds migrate across part of the area. Two wildlife zones, the Thelon Game Sanctuary in the east and Wood Buffalo National Park in the southwest, were involved. Great Slave Lake supports an established commercial fishing industry and a flourishing sport hunting and fishing business. The defined search area traversed one of Canada's most promising uranium prospecting zones, so that in many spots the natural background radiation was relatively high, introducing confusion into the search.

All of these aspects meant that search had to be rapid in order to recover material of potential harm to people or to the environment and its wildlife population. With no detailed information on the type of satellite or reactor the only safe assumption to make, once radioactive debris had been located, was that it should be sought on the ground and removed as quickly as possible to a controlled holding area. A number of government agencies were quickly involved because of jurisdictional responsibilities or of special capabilities. Functional coordination of all these bodies was required, and was provided by assigning to DND the lead role in the search, and responsibility for the total logistics of the undertaking. The Atomic Energy Control Board (AECB) was given the responsibility for recovery, handling and disposition of debris located, that is, for matters related to the health and safety of people and the environment. This joint operation, commonly referred to as "Operation Morning Light" at the time, but in this report as Phase I, was maintained until spring break-up forced a hiatus in the search on 20 April, 1978.

Following the spring break-up period, the summer or

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Phase II operations were carried out under contract by James F. MacLaren Ltd. (1)* under the AECB lead, closing down in mid-October, 1978.

This report covers the two Phases, focusing chiefly on matters related to health and safety of people and the environment.

The search and recovery operations and the ensuing analytical work produced a great volume of photographic records and detailed chemical and metallurgical analyses. A report such as this cannot include all the data but will offer typical information enabling the reader to learn the variety of material found, the extent of the search, the hazards presented by the debris, the precautions taken to minimize these hazards and the obvious lessons learned (APPENDIX H). The full analytical and descriptive records of all finds are on file in the AECB offices, and it is expected that they will be available for examination by interested persons. This may be delayed until certain international legal questions concerning the re-entry and the ensuing search have been considered and satisfactorily resolved.

The report also presents summaries of work carried out by others, with references when possible to published records.

Appendices provide details and background information that will be of interest to a spectrum of readers.

2. The Search Area and Search Organization

The general area in which debris might be expected if it survived the fall was rather clearly defined as a result of NORAD's computer predictions of the re-entry. The original area identified extended from near Yellowknife on Great Slave Lake to Baker Lake, some 800 km to the northeast. This was divided arbitrarily into eight numbered search sectors (Figure 1). As the search proceeded, and with ballistic calculations incorporating size and mass data from recovered fragments, the search area became better defined. Nothing was found in sectors 5 to 8 inclusive, but sectors 9 to 14 were added on the west and southwest as material was discovered in that area. Figure 2 (at back of report) shows the location of the several classes of debris found and will be useful for reference in connection with Section 7.

The total sectored area of search in the NWT was about 124,000 square kilometers; additional search was carried out in selected parts of northern Alberta and Saskatchewan.

Under DND lead, the Canadian Forces Base at Namao, near Edmonton, became headquarters for the search, and Yellowknife became the forward base for search flights and for handling recovered debris brought back by recovery crews. The aircraft and other equipment called in for the operation have been described elsewhere (2) but in summary there were 13 Canadian aircraft in action at the peak of the search effort. These included C-130 Hercules, CC-138 Twin Otter, and CC-115 Buffalo propeller craft; and CH-135 Twin Huey, CH-136 Kiowa, and CH-147 Chinook helicopters.

Although most of the main searches were based in Yellowknife, at various times men and equipment were also based in Baker Lake; near Warden's Grove on the Thelon River; and at several of the communities on the south shore of Great Slave Lake. A location on Cape Dorset, Baffin Island (in line with the satellite trajectory) where it was suspected for a time that a part of the satellite had fallen, was also investigated over a ten-day period. These requirements naturally led to a division of equipment and expertise that made staffing and supply even more difficult.

With the short notice provided, the full Canadian effort required a few days to be established, but a scientist from the Geological Survey of Canada (GSC) in the Department of Energy, Mines & Resources (EMR), experienced in air-borne exploration for uranium, was on site on 24 January. A team from the AECB was already in Edmonton when the presence of radioactive debris was first confirmed. The capability of immediately undertaking the operation was greatly enhanced by the availability within a day of an American team experienced in search and recovery of radioactive material. The offer by President Carter of this expertise was accepted by Prime Minister Trudeau early on 24 January, and U.S. personnel (to an ultimate maximum of about 120) moved into Edmonton. These personnel included the Nuclear Emergency Search Team (NEST), organized several years previously by the U.S. Department of Energy, which had in effect been preparing for the re-entry of Cosmos 954 for several weeks. The following day the GSC gamma-ray spectrometer for use in air-borne searching was flown to Edmonton from Ottawa, and subsequently approximately 30 scientists and technicians from the AECB, GSC and Atomic Energy of Canada Ltd. (AECL) worked with the Canadian Forces and the U.S. NEST in the search and recovery operations. DND with flight crews, maintenance and support crews, NAST, and command staff, peaked at about 250. Thus the total manpower involved in the field reached several hundred, and in addition to them a significant number of staff from the concerned departments were involved in discussions on planning and coordination in Ottawa. An Interdepartmental Steering Committee met weekly in Ottawa during Phase I, under the chairmanship of a senior DND officer. Major field organizational responsibilities may be summarized as follows:

DND — On-scene command — responsible for overall operations.

*Numbers in parentheses refer to APPENDIX I, References

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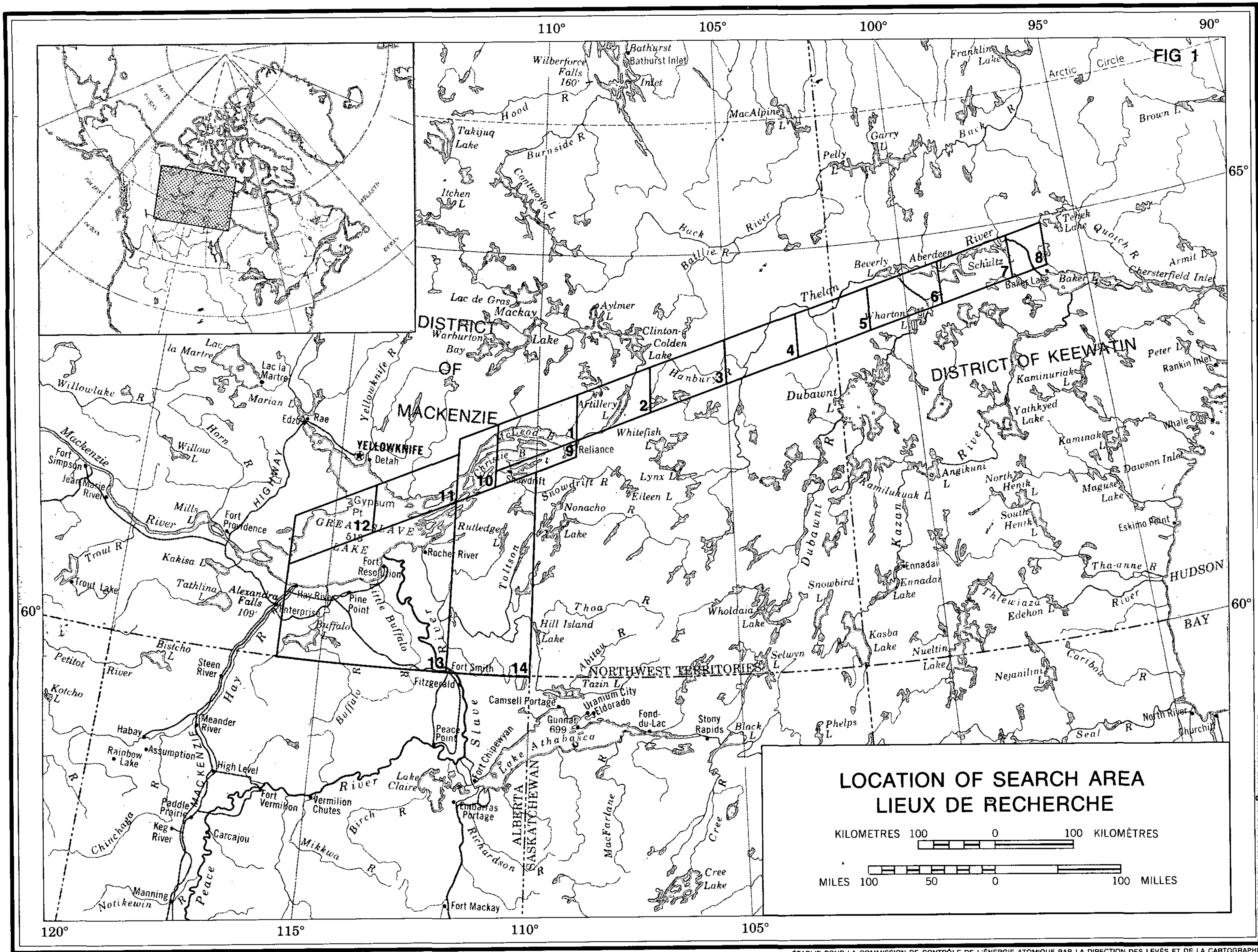

PRODUCED FOR THE ATOMIC ENERGY CONTROL BOARD BY THE SURVEYS AND MAPPING BRANCH, DEPARTMENT OF ENERGY, MINES AND RESOURCES, OTTAWA, CANADA.

ÉTABLIE POUR LA COMMISSION DE CONTRÔLE DE L'ÉNERGIE ATOMIQUE PAR LA DIRECTION DES LEVÉS ET DE LA CARTOGRAPHIE, MINISTÈRE DE L'ÉNERGIE, DES MINES ET DES RESSOURCES, OTTAWA, CANADA.

FIGURE 1 Location of area of fall, showing search sectors.

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AECB — Responsible for safe recovery, transportation and storage of debris.

EMR — Scientific management of the air-borne search under DND logistics command, using detection requirements established by AECB and other health physics groups.

For costs of the operations, DND assumed all expenses of the logistics — search flights, transport, man and material movements, establishment of access camps and fuel dumps — and AECB all expenses of its own, plus those of other federal departments (other than DND) that would become involved in matters of health, safety and the environment.

The successful completion of the Phase I operation reflects the immense effort by DND to meet both day to day exigencies and longer term plans. The fact that there were no accidents to people under search conditions underlines the thoroughness of the DND organization.

A brief chronology of the events from 24 January to 14 October, 1978 appears in APPENDIX A.

3. Roles of Other Federal Departments and Agencies

In addition to the effort of the GSC in supplying special equipment and expertise for the air-borne search and interpretation, other departments played a variety of roles. GSC staff have already published papers on the search techniques (3,4), and further reference to these will be made in this report.

AECL made major contributions to the program in several ways. All available shielded containers for radioactive material were provided for shipment of debris. Health physics and radiation monitoring staff were loaned to the AECB to augment its own limited resources. And most particularly, the Whiteshell Nuclear Research Establishment (WNRE) at Pinawa, Manitoba put its sophisticated analytical facilities at the disposal of the search and recovery operations. Eventually, essentially all samples recovered, large or small, were shipped to Pinawa for examination. This obviously interrupted ongoing programs, but WNRE proved a most willing helper in this work. This also provided a secure place for holding the satellite materials pending legal decisions on their ultimate disposition and for preventing radiation damage to the public or the environment. WNRE staff will be publishing detailed descriptions of debris (5); this present report will provide some examples of their work, but not full details. For much of the time during Phase I, a scientific representative from Defence Research Establishment, Ottawa, was also based at Pinawa to ensure proper liaison with the Edmonton base operations.

The Department of National Health and Welfare (NHW) contributed through the activities of the Radiation Protection Bureau (RPB). RPB already carries out air sampling at selected sites across Canada to measure radioactive fallout from nuclear test explosions; this was placed on a daily basis (for 24 days) after re-entry, and a new air sampling site was opened at Hay River during the search for Cosmos 954 debris. In addition RPB supplied a personal film dosimetry service for all involved Canadian personnel, and carried out laboratory studies under high priority to determine the hazards to people of minute radioactive particles that were found sprinkled over Great Slave Lake and the land to the south; RPB will be publishing a paper on the full results (6). Reference to this work will be made. RPB also monitored rain and snowfall, drinking water supplies in communities, and caribou meat from autumn hunting, for possible radioactive contamination. Personnel from the Department of Indian and Northern Affairs (INA) were involved because of their broad responsibilities north of 60° latitude, with respect both to the people and to the resources of the Territories.

Department of Fisheries and the Environment (DFE) staff considered aspects of environmental damage and undertook a program to monitor fish from Great Slave Lake for radioactivity.

An ice expert from National Research Council (NRC), Building Research Division, visited Cape Dorset to examine the reported occurrence that might have been related to the satellite but that was found to be a natural ice phenomenon (7).

The Ministry of the Solicitor General was involved because of the assistance available from the Royal Canadian Mounted Police (RCMP) in control of activities in the Territories, in communications, and in maintaining a supply of portable radiation-detecting instruments for travellers in the area. External Affairs (EA) was involved from the start as a result of the international implications of the event, and the intent ultimately to present a claim against the USSR for recovery of some or all of the large amounts of money spent on the search. Justice has advised on the legal requirements of "rules of evidence", under which all recovered material was handled, shipped and stored, and on the documentary requirements for the claim.

4. Acknowledgements

The search and recovery operations obviously depended upon the well-timed cooperation of a number of different federal agencies. In addition to a general acknowledgement of all the effort implied by the previous section, the AECB would like to recognize here specifically the cooperation of the Alberta Disaster Services, especially Mr. Ernie Tyler, the Alberta Dept. of Labour, particularly Mr. John Wetherill, Director of the Radiation Protection Branch, and the University of Alberta at Edmonton for analytical and data-processing assistance; the Saskatchewan Department of the Envi-

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ronment, particularly Mr. M.H. Prescott, Chief of the Environmental Protection Service; and the Government of the Northwest Territories in Yellowknife, particularly Mr. Dan Billing, Chief of Emergency Measures. Mr. Billing was always very helpful in general contacts and arrangements, and in arranging and coordinating public meetings in Northwest Territories towns.

There has already been reference to the participation of experienced U.S. personnel. In particular, the AECB acknowledges the valuable technical advice and support of health, nuclear and other physicists from Lawrence Livermore Laboratory, Los Alamos Scientific Laboratory, EG & G Incorporated, and the U.S. Department of Energy. Their previous specialized experience in nuclear radiation search and measurement was a salient feature of the speed with which search for debris got under way.

Finally, the interim storage of recovered debris at Namao, and its transportation to Winnipeg for pickup by WNRE personnel, put an extra load on the air crews of DND and the AECB expresses its thanks for an awkward service consistently performed without incident.

5. Radioactivity and the Implications of the Presence of a Nuclear Reactor

Radioactivity, to those unfamiliar with its parameters and behaviour, may be confusing, misunderstood, even frightening. Since the Cosmos 954 search and recovery operations relate almost entirely to possible radiation hazards, this section of the report has been prepared to provide the reader with some useful background information, and further basic information is given in APPENDIX B.

5.1 Radioactivity

"Radioactivity" is a term used to describe the emissions which accompany the spontaneous disintegration of an atom; materials that undergo such spontaneous disintegration are said to be radioactive.

The units used for reference and description of radiation in this report are given in Table 1. Although this report has generally used metric units for length, weight and volume it has been decided to use the older, existing units for radiation, since they may be more familiar to general readers.

Radioactive materials fall into two classes — naturally-occurring radioactive materials and man-made materials. *Naturally-occurring radioactive materials* are very widespread and include the uranium, thorium and radium found in rocks, minerals and soils throughout the world, and in certain products made from them; radium is also the source of radon which is a commonly-occurring radioactive gas. Furthermore, radioactive elements occur in the atmosphere, and cosmic radiation continuously arrives from outer space. These sources together produce a general background against which all radiation measurements must be made, and the result is the placing of a lower detection limit on the measurement of radiation from other sources. In North America, the average background reading is about 10 microrem per hour and an inhabitant of North America receives a radiation dose from all natural sources of about 100 millirem per year. For comparison, a patient undergoing one chest X-ray may receive 20 mrem. In the search area, where uranium-bearing rocks are common, natural background readings ranged generally from 5 to 25μ R/h, but in the trajectory area readings one hundred times the nominal background exposure were encountered, i.e. as high as 1 mR/hr at meter height.

TABLE 1

Radiation Units

Name of Unit	Abbreviation	Used to Measure	Commonly Used Units
curie	Ci	Rate of disintegration of a source. 1 Ci = 3.7 x 10^{10} dis/sec	millicurie (mCi) = 1/1,000 curie microcurie (μCi) = 1/1,000,000 curie
electron volt	eV	Radiation energy	million electron volts (MeV)
rem	—	Dose from all types of radiation.	millirem (mrem) = 1/1,000 rem
roentgen per hour	R/h	Rate of exposure to gamma radiation.	milliroentgen per hour (mR/h) = 1/1,000 R/h microroentgen per hour (μR/h) = 1,/1,000,000 R/h

Man-made radioactive materials have been produced either directly or indirectly by man; the radioactive materials associated with Cosmos 954 fall in this category, as do the fall-out products from nuclear weapons tests and the wastes from the nuclear power reactors.

Four types of radiation could have been associated with Cosmos 954: alpha and beta particles, gamma rays, and neutrons. These are briefly defined in APPENDIX B. An outline of the potential radiation exposure hazards is given in the next section, and further details appear in the APPENDIX.

5.2 Potential Radiation Exposure Hazards

When it became obvious that radioactive material had survived re-entry and might pose a threat to the health of inhabitants and wildlife, the potential radiation hazards to those coming close to fragments were recognized, as outlined in the following sections.

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(a) *External exposure of a significant part of the body*
Radiation exposure of a significant portion of the whole body could result from highly radioactive, large items. The magnitude of the dose would obviously depend upon the activity of the item, the distance from it, and the period of exposure at that distance. Smaller fragments would be unlikely to irradiate the whole body, but high exposure of parts of the body such as hands and feet would be possible upon close approach, or if a fragment were carried around in a pocket.

(b) *Contact or near-contact exposure of skin*
Such an exposure would result from picking up a radioactive fragment by hand, or by lodging of a particle in any part of the clothing. In such a case, the dose rate to the nearest parts of the body from even quite low activity sources could become significant. If exposure is prolonged over hours or days, the dose to the nearest tissue would be of concern.

(c) *Inhalation of small particles*
Tiny particles capable of entering nose or mouth might be inhaled, and if so would irradiate the lungs and perhaps other parts of the body.

(d) *Ingestion of small particles*
Ingestion might occur, for instance, during drinking or eating or by transfer from contaminated hands by cigarettes. If swallowed, radioactive particles would irradiate the gastrointestinal tract and perhaps other body organs.

These then were the considerations around which search criteria were required to be developed by health physicists. Their application is described in Section 6.2.

Instructions were issued to the population in the region to avoid and to report suspicious objects, in the light of the above hazards.

5.3 Reactor Aspects

During the operation of a nuclear reactor, a large number of radioactive isotopes (radionuclides) are produced by two different processes. When a neutron collides with and is absorbed by a fissile nucleus, such as that of uranium-235, the nucleus fissions (splits apart) into two lighter nuclei. The products of this splitting are referred to as *fission products*; some of these are stable isotopes but most are radioactive. When a neutron is absorbed by the nuclei of other, non-fissile materials in or around the reactor core as structural parts, these nuclei may become "activated", i.e. transformed into radioactive nuclei. The products of this second process are known as *activation products*.

Fission products from uranium-235 fuels commonly have atomic mass numbers centred around 90-95 and 135-140. The activation products encountered will depend on the composition of the materials close to the reactor core. In the case of Cosmos 954, stainless steel seems to have been used as structural material, and the most frequently encountered activation products have atomic mass numbers between 50 and 60 (that of iron is about 56).

The quantity of fission products formed in a nuclear reactor is proportional to the number of fissions that have occurred (and thus to the total energy generated).

The formation of activation products is also a function of the reactor power but is strongly dependent on the placement of the parent material relative to the reactor core as well.

The average rate at which the radioactive source, or radionuclide, decays is called the *activity* of the source. As more and more of the atoms disintegrate, there will be fewer left to disintegrate in the future, and the time required for half the atoms to disintegrate is called the *half-life*. Each radionuclide has its own half-life, but half-lives of different radionuclides range from fractions of a second to billions of years. Table 2 gives half-lives of the radionuclides encountered in Cosmos 954 debris.

As noted, radiation is emitted when an atom disintegrates spontaneously; usually, the radiation has a particular energy or group of energies. The distribution of these energies can be plotted to show the intensity at each energy; an example showing the energy distribution of the radiation from cesium-137 is given in Figure 3. Such a distribution is called the *energy spectrum* and is unique for a particular radionuclide so that the spectrum can be used to identify those radionuclides that are present — the spectrum is as distinctive as a finger print. This unique characteristic was used extensively in both the detection and the analysis of Cosmos 954 debris.

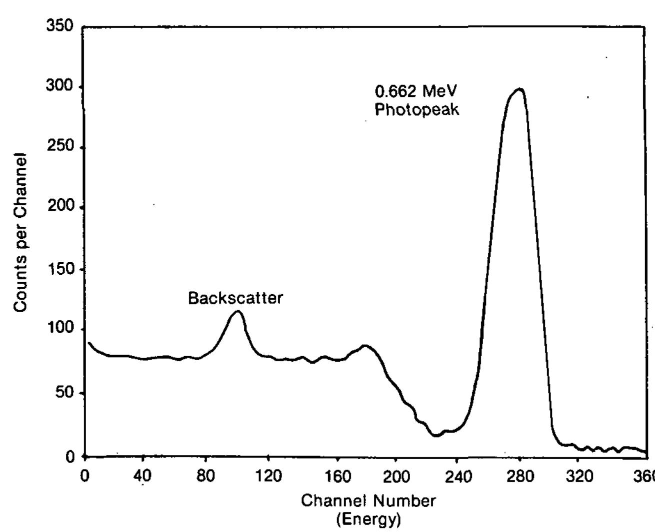

FIGURE 3 Sodium iodide energy spectrum for cesium-137

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TABLE 2

Fission and Activation Products in Cosmos 954 Debris and their Half-Lives[1]

(Chemical symbols given in parentheses)

Fission		Activation	
Isotope	**Half-Life**	**Isotope**	**Half-Life**
Strontium-89(Sr)	50.5 days	Chromium-51(Cr)	27.7 days
Strontium-90	29 years	Manganese-54(Mn)	312.5 days
Zirconium-95(Zr)[2]	64 days	Cobalt-58 (Co)	70.8 days
Niobium-95(Nb)[2]	35 days	Cobalt-60	5.27 years
Molybdenum-99(Mo)	66 hours	Iron-59(Fe)	44.6 days
Cesium-137(Cs)	30.17 years	Tantalum-182(Ta)	115 days
Barium-140(Ba)	12.8 days	Scandium-46(Sc)	83.8 days
Lanthanum-140(La)	40.2 hours	Antimony-124(Sb)	60.2 days
Cerium-141(Ce)	32.5 days	Plutonium-239(Pu)	24000 years
Cerium-144	284.4 days	Tritium	12.33 years
Ruthenium-103(Ru)[2]	39.4 days		
Ruthenium-106[2]	368 days		
Tellurium-132(Te)	78 hours		
Iodine-131(I)	8.04 days		
Neodymium-147(Nd)	11 days		

[1] The presence of residual uranium isotopes should also be recognized, though they play no significant role in this matter; uranium-235(U), 70 million years, and uranium-238, 4.5 billion years.
[2] Major fission products in Cosmos 954 debris.

5.4 Criticality

The neutrons produced by the fissioning of a uranium-235 nucleus have one of two essential fates; they may initiate additional fissions of other uranium-235 nuclei, or they may be lost (through absorption by non-fissile materials, or by escape from the system). With a large enough mass of fissile material, and/or with a configuration that curbs the loss of neutrons, the loss rate may be low enough to maintain a supply of neutrons for propagating the fission event, i.e. a chain reaction is produced. In such a state the assembly is referred to as "critical". Very high radiation fields would exist in the vicinity of such a "critical mass".

An immediate concern after the fall of Cosmos 954 was that a sufficiently large part of the core (if not all) might have survived re-entry and have achieved criticality, restarting the chain reaction. If, for instance, most of the core had landed intact and was able to melt enough ice and snow to become submerged in water, the mass might again have become critical. This is because the presence of water in effect cuts down the loss of neutrons. A mass of as little as 22 kg of highly enriched, undiluted uranium could become critical under these conditions. However, the results of the search quickly confirmed that the core had disintegrated so that criticality was no longer viewed as a likely hazard.

6. Air-Borne and Ground Searching

6.1 What To Look For?

A soon as the presence of debris on the ground had been confirmed, efforts were made to obtain from the USSR sufficient description of the satellite, and particularly of its power reactor, in order that the nature of potential hazards to people and the environment could be assessed. Without some guidance, search would be blind and perhaps misdirected.

The USSR quickly advised Canada that the reactor core contained uranium enriched in uranium-235, and later added that there had been a beryllium reflector. The core material was said by the USSR to be of non-explosive nature, formation of a critical mass being excluded. The reactor was also said to be designed so that on burn-up the active core would be dispersed into minute particles which would exclude the creation of radioactivity sources exceeding levels recommended by the International Commission on Radiological Protection. The USSR also stated that in their experts' opinions, the radiation levels resulting from any fallen material would be "practically" safe for people.

This information was useful in a general sense, but did not provide the total mass of material, nor the nature of the core, matters of prime concern when planning the extent of search and preparing for potential hazards that might be met. Some of the information arrived after the search operations had been in progress for some weeks. This meant that the sort of information desired had to be developed, as best as possible, as material was found and identified, and that certain assumptions were necessitated in regard to size of satellite and power of satellite. These assumptions will appear in the following sections of the report.

Although the USSR advice indicated that potential hazards were minor, the early finding of highly radioactive fragments dictated the necessity of a much more

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thorough search than might have been suggested by that advice.

As will be brought out later, the USSR subsequently provided some confirmatory comments on the numbers of certain types of fragments, after they had been found. Otherwise the interpretative processes required for hazard estimation have rested on the assumptions referred to above.

6.2 Objectives and Criteria

The basic objective of the search was to minimize the radiation exposure of people living in the area in accordance with the principles of radiation protection in general, and with the "as low as reasonably achievable" ("ALARA") principle recommended by the International Commission on Radiological Protection (ICRP; see APPENDIX B). A second objective was to minimize the radiation exposure of wildlife and generally to protect against ecological damage.

In developing guidelines, it was necessary to take account of the following important factors:

(a) the need for very stringent standards in areas of human habitation;
(b) the need for somewhat less stringent standards in other areas while still ensuring a high degree of protection; this would include consideration of the probability of exposure and the possible duration of such exposures;
(c) the possible exposure pathways as outlined in Section 5.2;
(d) the detection capabilities of the search instrumentation;
(e) the existence of widespread natural uranium and thorium mineralization;
(f) the significant quantity of fission products estimated to be involved;
(g) the radioactive decay of the fragments which gradually reduces the activity levels, so that the radiological significance of any undetected fragments will be reduced with the passage of time;
(h) the requirement to search by use of fixed-wing aircraft or helicopters, and by ground surveys, either on foot or augmented by road vehicles where conditions were suitable.

At the time that guidelines were originally formulated, limited information was available on the detection thresholds for each type of survey. It was estimated that the detection threshold for fixed-wing aircraft surveys was such that fragments with a gamma exposure rate of about 10-50 R/h on contact, or 10-50 mR/h at 1 meter, could be detected; and for the helicopter surveys, the detection threshold could be improved to detect fragments with a gamma exposure rate of about 100 to 200 mR/h in close proximity or 0.1 to 0.2 mR/h at 1 meter. In practice, it was possible to detect fragments at lower levels in certain circumstances; thus, the almost negligible background radiation levels over frozen lake surfaces during winter permitted improved detection by helicopter surveys in those areas and the absence of snow during summer permitted lower level flights by fixed-wing aircraft, which could follow the variations in the terrain more easily than during winter when visual flying was more difficult due to the absence of recognizable features.

6.3 Search Procedures

The first coverage of the probable impact zone was carried out by C-130 Hercules aircraft bearing gamma-ray detection apparatus. These planes flew a pattern of lines spaced 1 nautical mile (1.85 km) apart at an altitude of 500 meters above ground level. One Canadian (GSC) and three U.S. gamma-ray spectrometers were employed. The first confirmed radioactive debris was detected by the Canadian instrument on the night of January 26/27 in Sector 1 (on the ice, 27 km north of Fort Reliance). This instrument contained a sodium iodide crystal of 50,350 cm^3 volume, and its operation and sensitivity have been discussed by Bristow (3).

Data were collected during flight on magnetic tape, which was subsequently analysed by computer to identify the nature of the radioactivity, and to distinguish between natural and man-made radiation. As material was located, this search procedure sufficed to show that radioactive material was likely to be found only in a strip about a few kilometers wide, roughly centred in the originally delineated zone but corrected southwards for wind drift. Within this redefined area, subsequent searching was done, with microwave ranging systems to enable pinpointing of locations, on a more closely spaced pattern with lines spaced at 500 m and a nominal height above ground of 250 m. Precise location was a necessity so that the site of a "hit" could later be visited, usually by helicopter, to enable the find to be recovered. Removal was always carried out under the eyes (and instruments) of experienced health physics or radiation monitoring staff.

It was a helicopter that first encountered radiation from the tiny particles (near Snowdrift). The advantages of being able to fly slowly and much lower than the Hercules were quickly recognized, and helicopters were employed for surveys at altitudes of 15 to 30 meters to:

(a) locate precisely any radioactive fragments detected by the fixed-wing aircraft surveys;
(b) survey the environs of human communities situated within the search area;
(c) survey roads and railways within the search area.

Ground (on foot) surveys were conducted in inhabited areas, including camp sites, using portable survey instruments capable of detecting radiation levels of 1 to 3 μR/h above the natural radiation background.

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Where possible, the area to be surveyed was traversed slowly in a grid pattern. While slowly walking these grids, the surveyor gently swung the radiation meter back and forth across his path. This had the effect of increasing the effective area of detection and reducing the shielding due to ground surface irregularities. The spacing of the grid lines depended on the potential use of the area, the expected strength of the sources, background radiation and the type of area being surveyed. In areas with strong sources and low background (8 μR/h), a spacing of 4 to 6 meters was considered to suffice. In areas with high background (20 μR/h) and low level sources, traverses as closely spaced as 1 meter were needed to ensure a reasonable level of particle detection.

In each community surveyed, grids were walked in all public and private areas with the exception of the roads and inhabited streets surveyed by a vehicle-mounted detection system. Attention was given to drip-lines, gutters, drains, snow fences, shrub-lines, snow dump sites and any other areas that appeared to have the potential for particle accumulation. Special attention was also paid to "sensitive" areas such as schoolyards, playgrounds and gardens as well as high traffic public areas, such as restaurants, municipal buildings, and food stores. Roofs of public buildings, hospitals and other areas with the potential for particle accumulation and exposure of large numbers of people were also surveyed. Lots that were uninhabited at the time of survey were searched if they had been cleared, or if their future use appeared likely.

In addition to coverage of communities and associated areas, a large number of other sites were investigated. These included cabins, hunting and fishing camps, lodges, mining and prospecting camps and fuel cache sites — in general terms, any area which might be frequented by man. A total of 130 remote sites were investigated. Based on data supplied by INA a list of sites for Phase II survey was prepared, and was supplemented with information from local government officials and RCMP, citizens' requests, and the consultant's inspection of the area. The area of required coverage was vast, extending over all of the territory south of Great Slave Lake and into northern Alberta and Saskatchewan. In addition, a number of sites situated on the islands in the east arm of the lake and on the north shore of McLeod Bay were investigated. A number of lodges and cabins south of the lake had been visited during the Phase I operations but repeat surveys were deemed necessary during the summer months to ensure complete coverage.

Ground vehicle surveys in Phase II were conducted with radiation detection equipment installed in vans, a procedure used on highways, roads and streets. On railroads, the detection equipment was mounted on a special track vehicle. Under winter conditions, ploughing of roads pushed snow and anything it contained to the passenger side of the route, and in the summer search instruments were mounted on this side of the vehicle. The vehicle could, of course, traverse in both directions, thus covering both sides of the road. The detectors were linked to an array of electronic equipment including a visual display which indicated the levels of radioactivity being measured. The detection equipment was initially calibrated with a standard cesium source and then checked in the field with "hits" found during the ground survey of Hay River.

Based on the field tests, a vehicle speed of 15 km/h was chosen as a satisfactory compromise between sensitivity of detection and speed of operation. The vehicle speed was later reduced to 8 km/h in the Fort Smith area and Wood Buffalo National Park as particle size and radiation strength decreased.

The principal instruments used for ground survey purposes are listed in APPENDIX C, according to the application, with the name or type of instrument and model number, brief information on the detector and range of readout, and the name of the manufacturer. Similar to the ground survey instruments, the principal component of the vehicle detection equipment consisted of sodium iodide scintillation crystals. However, whereas the hand-held instruments contained crystals of approximately 45 cm^3 volume, the vehicle crystal volume was approximately 13,600 cm^3. Furthermore, the vehicle system, like the air-borne system, was designed to discriminate between natural background radiation and radiation produced by Cosmos debris.

6.4 The Air-Borne Detection of Radioactive Debris*

It is a characteristic of fission products of a reactor that they emit gamma radiation with a higher proportion of low energy gamma-rays than those emitted by naturally occurring radioactive isotopes. Gamma rays from neutron activation of elements present in steel are also predominantly low in energy. Figures 4a and 4b compare a typical natural gamma-ray spectrum and a fission product spectrum, which illustrate this point. Table 3 shows the major gamma-rays emitted by fission and neutron activation products which are most likely to be observed soon after reactor shut-down. The half-lives of the various isotopes are also indicated.

Because of the high levels of radioactivity of rocks in the search area, mainly due to potassium-40 and decay products in the thorium series, a ratio technique was used to distinguish between natural and artificial sources of radiation. This ratio technique makes use of the fact that the radioactive satellite debris is dominated by low energy gamma-rays. The ratio of all gamma-rays

* Permission of the GSC and the author of reference 4 to use the text and illustrations of Section 6.4 is gratefully acknowledged. Slight modifications have been introduced by the editor.

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TABLE 3

**Some Gamma-Ray Emitting Isotopes
Likely to be Observed Following Reactor Shut-Down**

Isotope	Gamma-Ray Energy (keV)	Half-Life (days)	Origin
Zirconium-95	724,756	64	Fission
Niobium-95	765	35	Fission and decay product (daughter of zirconium-95)
Ruthenium-103	497	39.4	Fission
Cobalt-58	810	70.8	Activation of nickel-58
Manganese-54	835	312.5	Activation of iron-54

detected with energies between 300 and 1400 keV to those from 1400–2800 keV was found to remain relatively constant for all natural sources of radioactivity even while passing from water to land (Figure 5a). The radioactivity over water arises from cosmic radiation, the radioactivity of the air, the aircraft and its equipment (radium dials, etc.). Radioactive satellite debris is indicated by a significant increase in the low/high energy ratio (Figure 5b). Additional confirmation is provided by the increase in total radioactivity.

Bristow (3) describes in more detail the procedures that were used to detect the radioactive satellite debris.

7. Description of Recovered Debris

7.1 General

Table 4 summarizes the nature of material found in the search. Simply by analogy with other earth-orbiting satellites, Cosmos 954 has generally been assumed to have weighed in the order of 4 or 5 tons; the amount of material recovered (about 65 kg) is not only a small fraction of the whole but obviously represents for the most part a few special parts of the satellite. Most of the general structural components, presumably of steel, have not been found, and it is surmised that these components have oxidized to a finely-divided powder, or "burned up", during re-entry. On the other hand certain beryllium cylinders have suffered little if at all during re-entry.

Individual identification of each recovered fragment is given in APPENDIX D, Summary of Fragments Re-

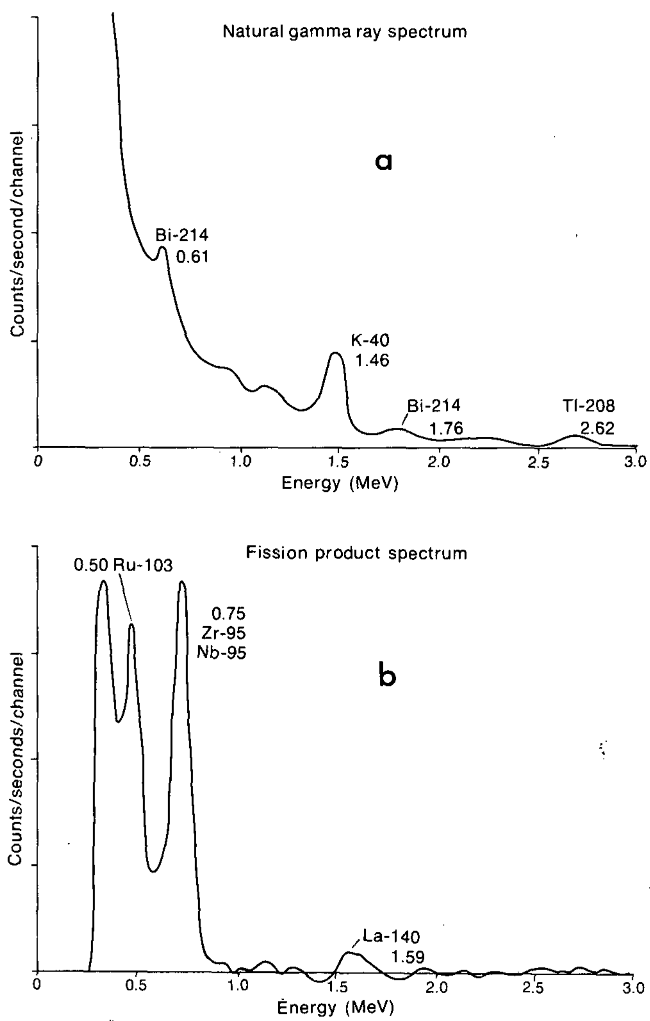

FIGURE 4 Typical natural (a) and fission (b) product gamma-ray spectra.

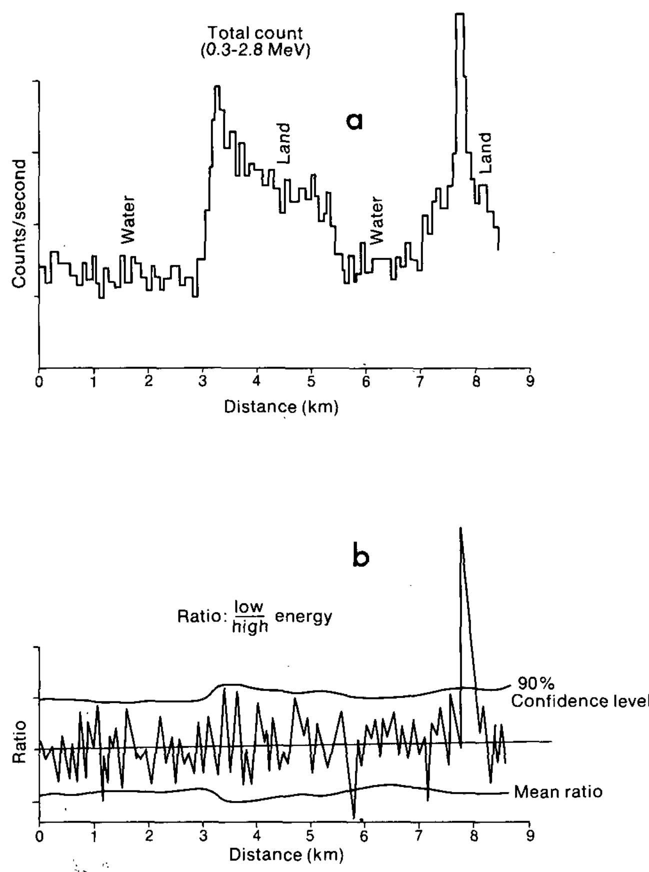

FIGURE 5 Example of procedure used to detect radioactive satellite debris (the high peak in each case).

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covered; this gives sample identity as a "Hit Number"*, the location, the in-situ radiation field, and some physical description. This is the "Hit List", with spurious records and natural occurrences deleted.

Figure 2 (map at back) indicates the locations and pattern of distribution of fragments.

In spite of the relatively small amount of material recovered, its safe disposition for shipping purposes put a great strain on available lead-lined containers. A description of container types and of the careful procedure followed in moving debris from Edmonton to WNRE at Pinawa is given in APPENDIX E.

The recovered material divides itself into two rather distinct classes, as suggested in Table 4, and they will be treated separately in sections 7.2 and 7.3.

In the following sections of the report, examples of both types of debris are described with particular reference to the information provided by WNRE. At WNRE each item was put through part or all of a complex analytical examination scheme. It was monitored for radioactivity, photographed and given a brief description. Simple tests were done to determine its character, for example density, magnetic susceptibility, and electrical conductivity. Where appropriate, samples were taken for further analysis and radiochemical measurements. Because of radioactivity, many of these operations had to be done inside a shielding "hot-cell" equipped with remote manipulators and a leaded-glass window.

Samples taken for further study were analyzed by gamma spectrometry for radionuclides present, by X-ray and emission spectrography for their elemental composition, by electron microscopy and X-ray diffraction for structure and morphology, by mass spectrometry for nuclear fuel content and by chemical and other instrumental analysis for a variety of other information.

The result was that a great deal became known about the character, identity, and potential hazard of the variety of items that survived re-entry. Identification of alloys used in the satellite was possible (and in some instances even the method of fabrication became apparent). The solubility in hot and cold water and likely behaviour of radionuclides in nature was also investigated.

TABLE 4

Summary Description of Debris Recovered

Material	Size, Weight	Radiation Level When Found	Sector
Large Fragments			
4 steel plate fragments	largest 225 mm x 75 mm x 6.5 mm weighing 272 g.	To 200 R/h on contact	1, 11, 12
41 beryllium rods (some with niobium sheaths)	100 mm x 20 mm diam. About 51g each	600mR/h to 100R/h on contact; 30 to 150mR/h at 1 meter	1(17 rods), 2(21 rods), 10(3 rods).
6 beryllium cylinders	250 mm x 100 mm diam. 3.6 kg. each	5 to 15R/h on contact. 40 to 800 mR/h at 1 meter	2(5 cyl.) and 3(1)
Tubes, rods, plate (the "antlers")	6 rods about 1 meter long attached to plate. 20 kg. total	To 15R/h on contact. Variable over the debris	4 (near Warden's Grove on Thelon River)
Steel tube (the "stovepipe")	About 500 mm long, 360 mm diam., 2.5 mm wall. 18.2 kg.	Non-radioactive	1 (near Ft. Reliance)
Other Chunks, Flakes, Slivers	Variable	Most 10 to 30 R/h on contact; one to 500R/h	Chiefly 10
Small Particles			
About 4000 recovered	a) spherical, 1mm to less than 0.1 mm diam. Mass 5 mg to less than 100 μg b) irregular, or flaky. Some several mm on a side and very thin and friable	most in the range 10 to 100 mR/h at 1 meter	10,11,12,13,14

The first class — the larger objects — were found in a narrow zone stretching from roughly the centre of Great Slave Lake to Artillery Lake; an isolated object was found on the Thelon River near Warden's Grove. This is a total distance of well over 500 km.

The second class comprises smaller particles whose landing was affected by the wind currents in action at the time. They were thus carried far to the south of the landing path over an area of 100,000 square km or more.

* The identification code, often used as a sample number, indicates "Morning Light" (ML), and the sequential position of the item in the series of fragments recorded in a sector, e.g. 1(1) is the first item in sector 1, 7(3) is the seventh item in sector 3, and so on.

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covered; this gives sample identity as a "Hit Number"*, the location, the in-situ radiation field, and some physical description. This is the "Hit List", with spurious records and natural occurrences deleted.

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The first shipment arrived at WNRE on 5 February, 1978; 15 major shipments in all were received. More than 4700 analyses were reported, and more than 40 scientists and support staff were involved at one time or another. A measure of the total is provided by the number of man-hours recorded for analysis and operations such as handling and storage; the figure exceeds 9000.

WNRE's final storage actions completed the sequence of careful identification and control of samples from their first discovery to their ultimate disposition in storage facilities. This provided the final entry on the travelling form shown in Figure 31, APPENDIX E.

7.2 Large Fragments

7.2.1 Location

Fragments were found in a well-defined band as shown in Figure 2. Generally the size and weight of fragments increased towards the east end of the trajectory, consistent with ballistics considerations.

Most of the small beryllium rods were clustered over a distance of 75 km. The beryllium cylinders also occurred as a group over about 60 km. The fragment referred to as the "antlers" was the largest fragment recovered and the furthest east on the track. The four recovered steel plate fragments were widely scattered (over 300 km); one (in sector 12) was the most westerly object found.

The miscellaneous smaller pieces, mostly from Sector 10, vary greatly in shape and size.

The fragment known as the "stovepipe", the only non-radioactive debris located, was spotted by eye by chance in Sector 1 during a flight to another location.

7.2.2 Description of Selected Fragments

Typical fragments of each type are described in detail in the following sections along with results of analyses performed on them. For space-saving purposes, use is made of the chemical symbols for elements, as listed in Table 2. It should be noted that radiation readings are meter readings, not corrected for background.

Steel Plate Fragments

The largest steel plate, ML-1(1), is an oblong fragment, about 225 mm by 75 mm by 6.5 mm thick, weighing 272 g and with a density of 5.3 grams per cubic centimetre (see Figures 6 and 7). The object has a convex-concave surface on which a slag-like material had been deposited. It appears to be part of a large cylinder with the axis of the cylinder parallel to the longest dimension of the plate. The presence of the slag layer and the appearance of the edges of the plate indicate that extensive melting and resolidification has occurred. It was determined by emission spectroscopy that the main plate material is an austenitic stainless steel similar to American Iron and Steel Institute Type 321. An analysis of the slag-like material showed that it is an oxidized form of the same material.

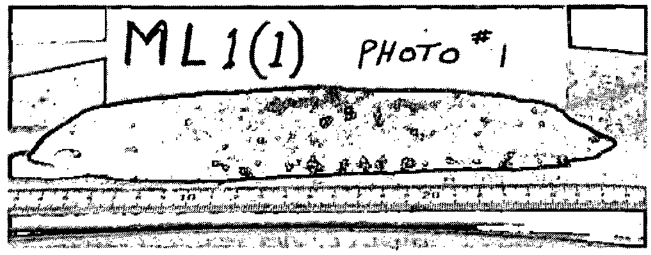

FIGURE 6 Convex side of steel plate fragment ML-1(1).

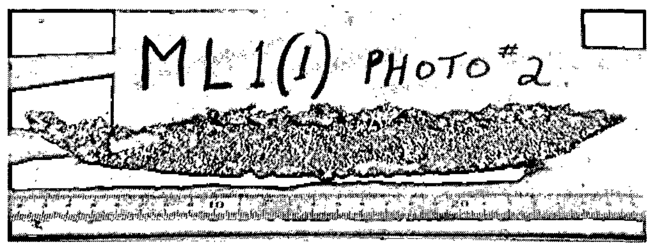

FIGURE 7 Concave side of steel plate fragment ML-1(1).

A few small granules of uranium-rich material were also embedded in the slag layer. These were later shown to be similar to recovered fuel particles.

The in-situ radiation field of ML-1(1) was measured as high as 200R/h near contact. However, the radiation field was not uniformly distributed over the convex and concave sides; at near contact it was found to vary from 1 R/h to 200 R/h of beta/gamma radiation over distances as short as 5 mm.

Gamma spectrometry measurements showed that the major activity from the main plate material came from activation products, while fission products and activation products in about equal amounts contributed to the activity of the slag-like material. Quantitative activity measurements were made on samples taken from different areas of the plate: on a piece of main plate material dissolved in an appropriate solution, on a piece of slag material similarly dissolved, and on loose granules which were easily detached from the main plate (Table 5).

The activation products are those expected with stainless steel. Other radionuclides are typical fission products in irradiated fuel and were mostly located between the main plate metal and the slag-like coating. This area was found (by beta/gamma autoradiography) to possess especially high activity.

Another plate-like fragment (ML-1(12)) is shown in Figure 8. This object was found further west than any other. It is also stainless steel but does not exhibit the same degree of overheating as ML-1(1).

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TABLE 5

Quantitative Activity Measurements on Portions of Steel Plate ML-1(1)

(Activities in millicuries per gram)

Portion	Plate Metal Dissolved	Slag Dissolved	Loose Granules
Date Counted:	13 Feb. 1978	13 Feb. 1978	15 Feb. 1978
Activation Products			
Cr-51	2.3	1.5	1.52
Mn-54	1.4	0.3	0.54
Co-58	8.4	2.7	N.D.*
Co-60	0.02	0.04	N.D.
Fe-59	0.09	0.08	N.D.
Fission Products			
Zr-95	0.11	0.54	1.4
Nb-95	0.54	0.57	1.3
Ru-103	0.65	0.32	1.3
Ba-140	0.51	1.5	N.D.
Ba/La-140	N.D.	N.D.	4.9
Ce-141	0.06	0.78	1.2
Mo-99	0.01	N.D.	N.D.

*N.D. = not detected.

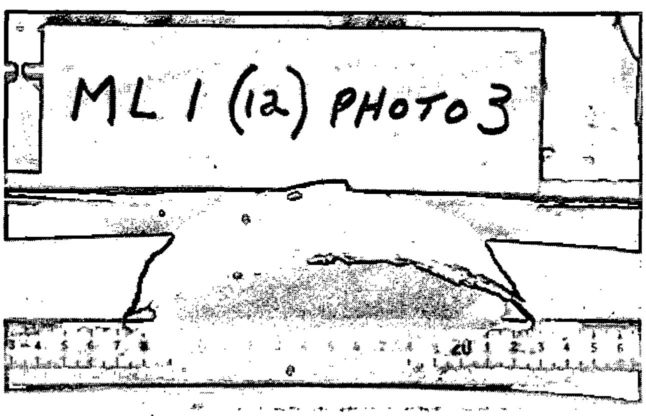

FIGURE 8 Steel plate fragment ML-1(12) showing surfaces less damaged by re-entry.

Judging by the level of activation product activity, the four plate fragments that were found originated near the periphery of the reactor core.

Beryllium Rods

As previously mentioned, the largest group of similar fragments recovered comprises 41 beryllium rods which all fell in their own portion of the "footprint" of the satellite (see Figure 2). These were apparently all about 100 mm long and 24 mm in diameter, and weighing about 50-55 g with a density of about 1.8-1.9 g/cm^3. Rods appear to have been separate, individual slugs and not the result of break-up of longer bars.

Surfaces were commonly scorched, with evidence of some material having become molten and then resolidifying. Some were noticeably shortened and rounded, indicating ablation. Remnants of a shiny corrugated cladding were observed on many rods, and some pieces of cladding were also recovered separately. Figure 9 shows a partly burnt rod still in its cladding.

FIGURE 9 One of 41 beryllium rods, still with a niobium cladding, as it was found lying on the snow on 7 February, 1978.

A metallographic transverse cross-section of one rod showed that it was solid throughout. The major impurities were iron, tin and zinc, with total impurities being less than 1% by weight. A similar analysis on an example of the cladding (ML-12(1)) showed it to consist largely of niobium metal with beryllium and lesser calcium and iron as major impurities.

In the body of the rods, activity was found mainly to be due to activation products, with Cr-51 and Sc-46 being most intense, and a small amount of fission products. Surfaces showed mixed activation and fission products. Quantitative gamma spectra counted around 15 February 1978 from three samples taken from two different rods gave the following results (Table 6).

Except for Ta-182, an activation product of naturally-occurring Tantalum-181 and often associated with niobium, all activation products relate to the impurities detected in the beryllium of the rods. The fission products and Ta-182 are probably contamination from remnants of the cladding still adhering to the Be rods.

Two pieces of cladding were analysed: ML-12(1) and a piece detached from ML-11(1). The quantitative analysis of ML-12(1) gave the following results (as of 20 February 1978) (Table 7).

The major gamma activity is due to Ta-182. Most of the remaining activity is from fission products deposited on the surface of the cladding.

TABLE 6

Radionuclides in Beryllium Rods

(Activities in microcuries per gram)

Sample	Sc-46	Cr-51	Mn-54	Fe-59	Co-58	Co-60	Te-132	La-140	Ta-182
ML-5(1) (metal)	2.1	7.7	0.4	0.3	0.4	0.2	0.001	0.03	0.08
ML-11(1) (metal)	1.0	3.8	0.4	0.2	0.5	0.2	ND*	present*	present
ML-11(1) (Surface plus metal)	10.0	4.3	1.0	0.1	0.05	0.2	ND	ND	present

*ND = not detected; "present" = detected but too low to measure

TABLE 7

Radionuclides in Niobium Cladding ML-12(1)

(Activities in microcuries per gram)

Mn-54	Zr-95	Nb-95	Ru-103	Te-132	I-131	Ba/La-140	Ce-141	Ta-182
5.4	27	73	46	43	24	27	Present	81

TABLE 8

Radionuclides in Melted Snow Recovered With Beryllium Rods

(Activities in millicuries per litre)

Sample	I-131	Cs-137	Ba/La-140	Ru-103	Ce-141	Zr-95
ML-6(1)	2.7	0.57	3.5	0.03	N.D.	N.D.
ML-24(1)	0.02	0.01	0.35	N.D.	0.003	N.D.
ML-6(2)	0.07	0.003	0.09	N.D.	0.01	N.D.
ML-7(2)	0.46	0.78	5.1	N.D.	0.02	N.D.
ML-8(2)	0.35	0.05	0.57	N.D.	0.03	0.03

Major gamma activity on the piece from ML-11(1) was from Ta-182 but Co-58 was also present; among the fission products detected Ru-103 was most intense and at lower levels were Ba/La-140 and Ce-141.

During Phase I, it was commonly the case that snow and ice adhered to recovered debris, and were enclosed in the container used for transport. In several instances the resulting water was analysed to estimate contamination around debris. With respect to beryllium rods the accompanying water was found to carry mostly fission products, some of them of the volatile type. Table 8 illustrates the nature of such contamination (counting date 20 February, 1978).

The role of these beryllium rods in the reactor is not known. However, they were possibly part of the reflector which the USSR stated had existed.

Beryllium Cylinders

Six large and apparently identical beryllium cylinders were recovered, from a cluster of sites. They are about 100 mm in diameter and 250 mm long, and weigh about 3.5 kg. Each end has six short identations equally spaced around the circumference and the indentations on opposite ends are lined up. In addition, one end has a circumferential groove (Figure 10).

A chip taken from one edge showed the material to be beryllium, with about 100 ppm of aluminum as the major impurity. Both longitudinal and transverse sections were cut from one cylinder, confirming that they were solid (the tapered end on some had suggested a capping)*. Emission spectroscopy results on sections also confirmed that they were homogeneous in composition.

Gamma spectra recorded for surfaces of three of the cylinders showed the activity to consist of mixed activation and fission products where the surface was dirty, but only activation products from clean surfaces. Some of the fission products detected were Zr/Nb-95, Ba/La-140, Ce-141 and Cs-134, but their activity level was always lower than that from the activation products, mainly Ta-182, Sc-46, Co-60, Co-58, Mn-54 and Fe-59.

* This procedure also confirmed that unless such operations are carried out under the most stringent control, contamination by beryllium dust results, and may become rather wide-spread before it is recognized. The clean-up procedure once the dust has spread is a major undertaking.

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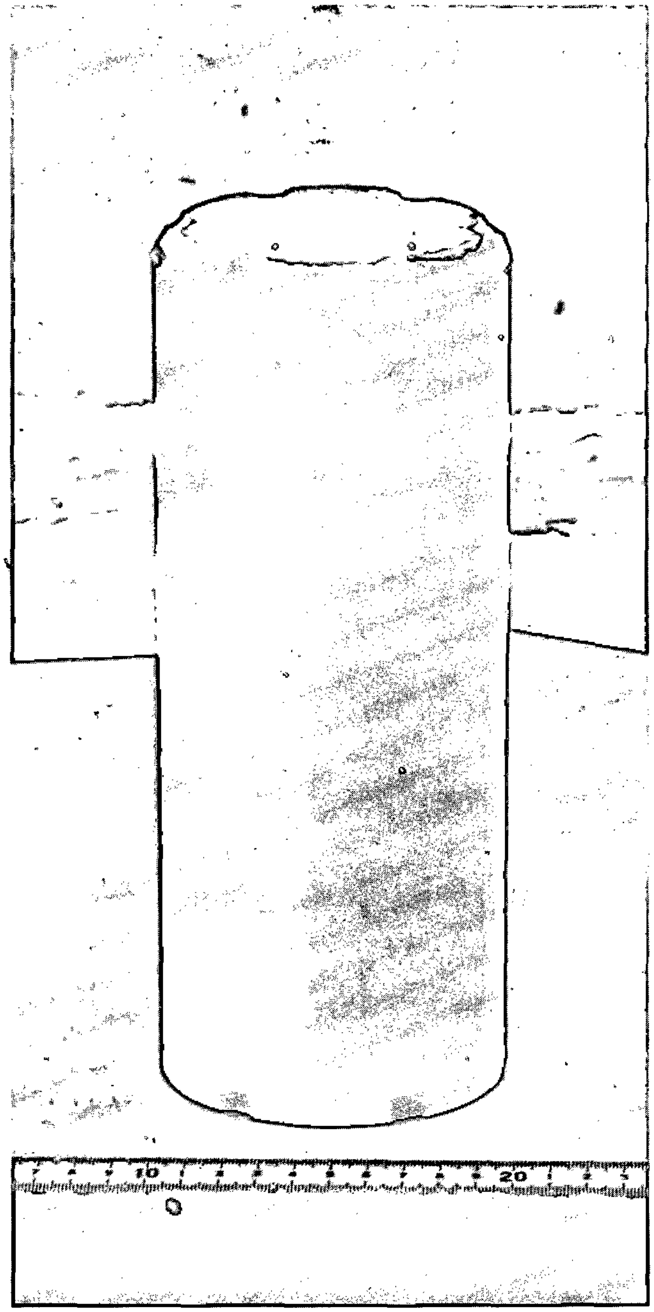

FIGURE 10 One of six beryllium cylinders, ML-29(2). Note the generally unaltered appearance of the surface.

The exact role of these large beryllium cylinders in Cosmos 954 is unknown, although again they were possibly associated with the reflector. The excellent condition in which the cylinders were recovered contrasts with the extensive damage received by the smaller rods and suggests that they were more protected during re-entry.

"Antlers"

The largest satellite fragment (actually in two pieces) found was the complex structure shown in Figures 11 and 12 and nicknamed the "antlers". This was the material fortuitously discovered by two of a group of six men wintering on the Thelon River.

The structure consists of six legs or tubes, three still attached to a circular base plate and three others which apparently broke loose on impact. When attached, the 700 mm legs were held about 125 mm apart by four rows of cross-braces. Much of the exterior surface was covered by a white powder which was determined by powder X-ray diffraction to be hydrated lithium hydroxide, $LiOH.H_2O$. Darker deposits on the antlers were analysed as lithium hydride, LiH. The cross-braces were found to contain both LiH and $LiOH.H_2O$. Samples from the base plate and from the legs were analyzed by emission spectroscopy and found to be made of stainless steel with a composition similar to that of other fragments.

To ensure that the legs of the "antlers" did not contain hazardous materials, and, if possible, to aid in definition of the "source term", legs were cut open. Cross-sections (Figure 13) revealed that each leg (about 33 mm. diameter) carried an inner tube (about 25 mm diameter), the annulus between being filled with a black powder (either boron silicon carbide or boron carbide, or both). The inner tube in turn held a jointed arm that was independently movable, and of which tubular sections held either the black powder or lithium hydride.

The size of the "crater" associated with the "antlers" and its distance down the trajectory were both anomalous. However, both may be explained by the large amounts of lithium hydroxide found. It has been calculated that the assemblage could have contained as much as 50 kg of lithium hydride which would have reacted, after impact, with melted ice in a very vigorous (exothermic) chemical reaction, spattering the products over a large area and producing the "crater"*. Furthermore, the distance that the "antlers" travelled down the trajectory is a result of the extra mass of lithium hydroxide present while in flight.

The complex structure of the whole assembly seems consistent with a reactor control function. The boron-rich link on the movable rods suggests that these were reactor control or shut-off rods. The large amount of lithium hydride would have provided a neutron shield for the satellite's electronic components.

* When the "antlers" were first found, their nature and the size of the "crater" suggested the possibility that part or all of the reactor core might be present as well, under the ice. A neutron-detecting device on an extension cable was therefore flown to the site and inserted through holes drilled through the ice. It was discovered that the river was relatively shallow in that spot, and a thorough search failed to locate any foreign material or radiation. Subsequently, as will be explained in a succeeding section, the discovery of the small particles of fuel showed that the core had disintegrated far to the west and at some elevation above land.

DFE Water Survey personnel sampled the river water above and below the "crater", and analysis by the University of Alberta laboratory in Edmonton failed to show the presence of radionuclides. With removal of the "antlers" and all possible smaller debris in the area, the potential for contamination of the water was largely eliminated.

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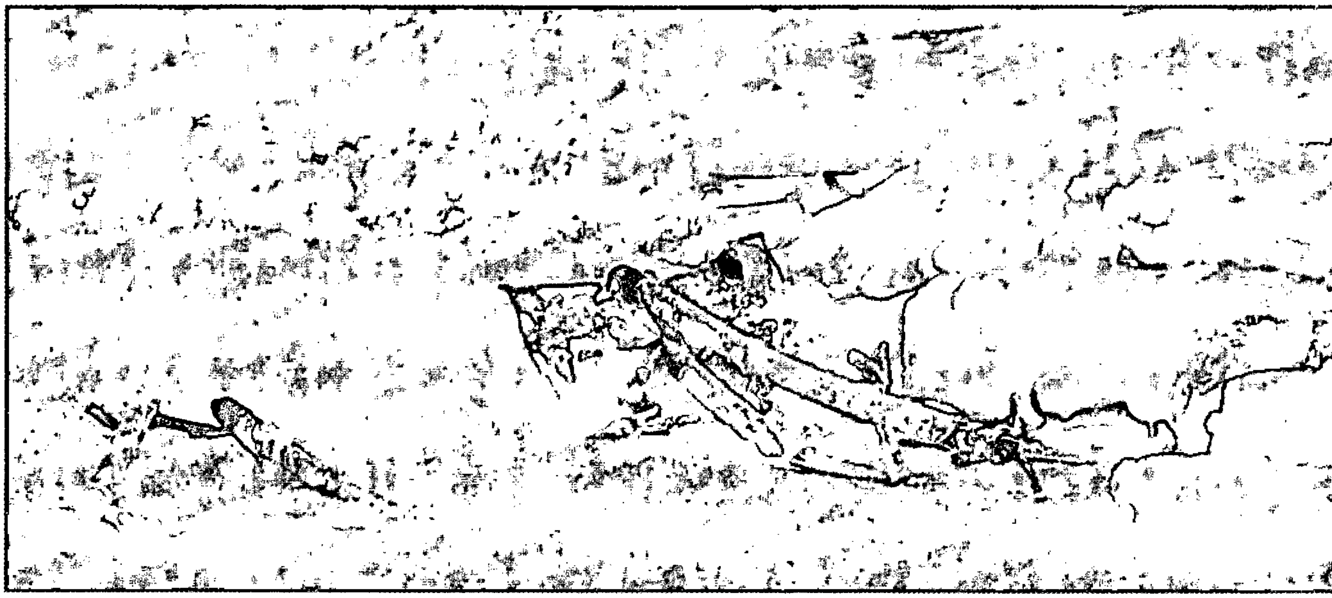

FIGURE 11 The "antlers" as discovered in ice and snow on the Thelon River; photographed 29 January 1978.

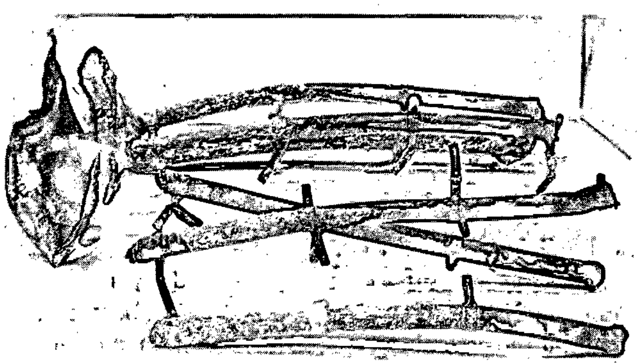

FIGURE 12 The "antlers" photographed at Whiteshell Nuclear Research Establishment. The white coating is hydrated lithium hydroxide.

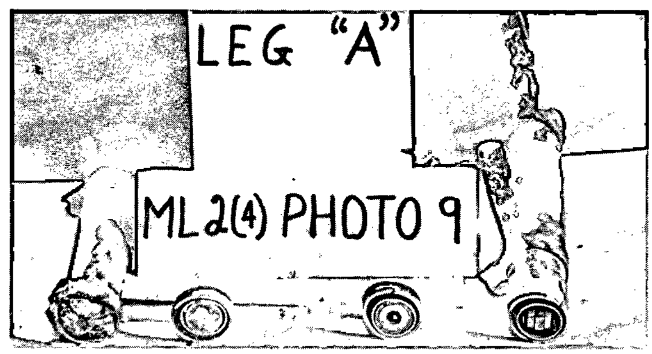

FIGURE 13 Cross-sections of one of the legs of the "antlers", resulting from studies to ensure that they did not contain unexpected hazardous materials.

"Stovepipe"

The "stovepipe" is shown, as found, in Figure 14. It is simply a large empty pipe about 500 mm long (varies from 420 to 510 mm due to uneven erosion during re-entry) by 360 mm diameter with a wall thickness of 2 to 3 millimetres. One end is jagged and shows evidence of extensive melting, the other end is terminated by a machined flange or rim. The rim also appears to have been partially melted during re-entry, and then resolidified. Other fragmented and charred debris was recovered nearby and when reconstructed (Figure 15 page 18) appeared to form a fibrous seal over the rimmed end.

Apart from the non-metallic (probably thermosetting plastic) material assumed to have capped the flanged end of the pipe, the metal is apparently a mild steel; one area exhibited a fully developed martensitic structure. A factory marking on the pipe is shown in Figure 16, page 18, with one apparently Cyrillic letter (ya) shown.

This fragment was not radioactive and must therefore have belonged to a part of the satellite not closely associated with the reactor. Because it presents no hazard to people this fragment was placed on exhibition in the National Museum of Science and Technology in Ottawa, Ontario, in October 1978.

Other Chunks, Flakes, Slivers

One curious fragment nicknamed the "moose hoof", is shown in Figure 17 page 19. It is basically a truncated solid cylinder of about 100 mm in diameter and 60 mm along its maximum length, bisected by a 45° plane. It is cut by a groove about 20 mm wide and about 50 mm deep. It was heavily covered with a black flaky deposit.

Emission spectroscopy results on the metal indicated only the presence of beryllium (consistent with a density measurement).

Gamma radiation was 6 R/h, near contact. Two portions were subjected to gamma spectroscopy. The first sample consisted of a piece of the black flaky deposit, in which activity was mainly due to the usual activation

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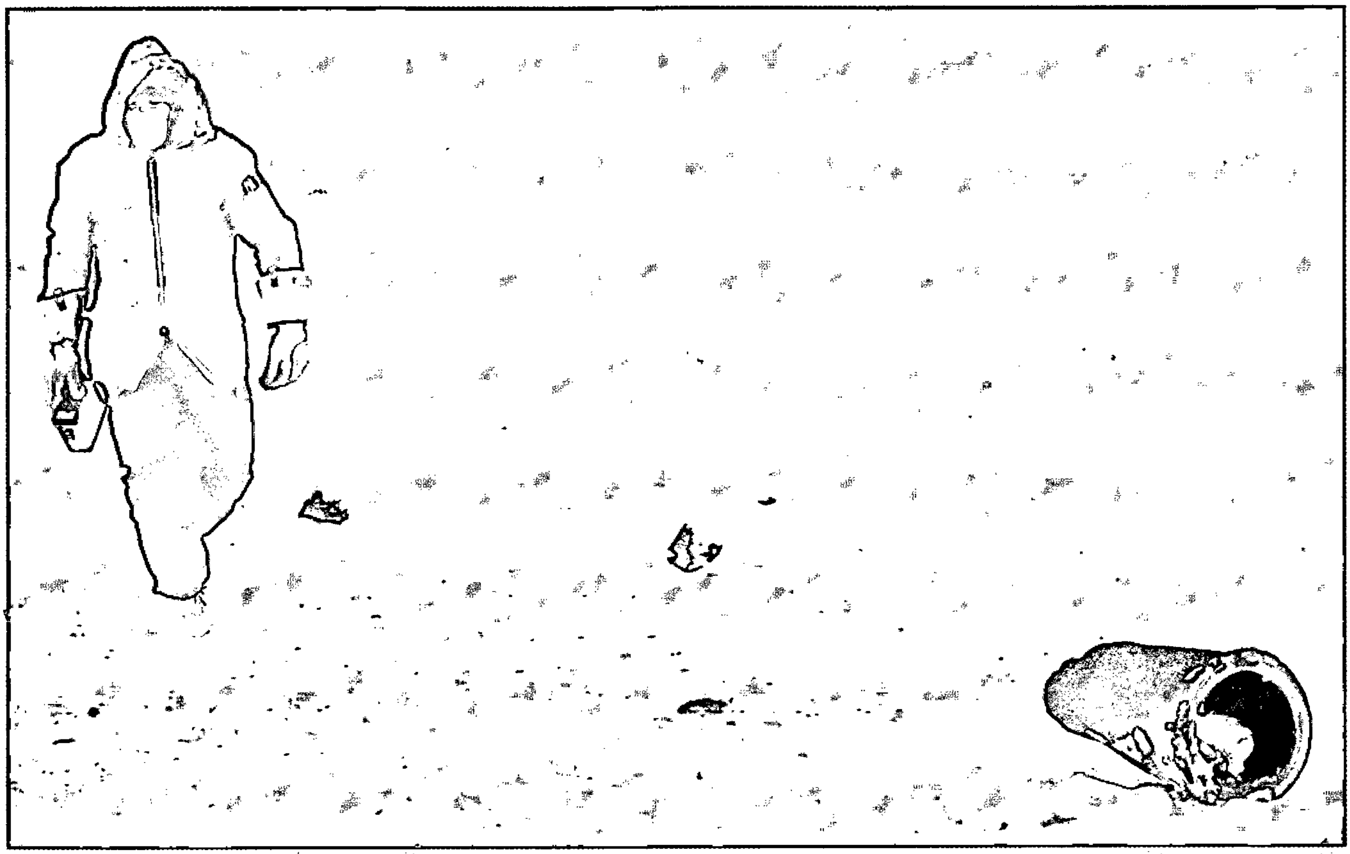

FIGURE 14 The "stovepipe" surrounded by smaller and more fragile debris on the frozen surface of Great Slave Lake.

products of steel, and to fission products (Ce-141, Ru-103, Ru-106, La-140, and Zr/Nb-95) at lower levels. In the second sample, of clean metal, the activity was mainly due to fission products, Ce-141, Ru-103, Zr/Nb-95, Ba/La-140, Ce-144, and some steel activation products at lower levels.

Other fragments were generally very small and of irregular shape. Judging from the radiation fields measured and the type of fission products detected they must have been in or near the reactor core. One such fragment (ML-3(10)) is shown in Figure 18 page 19. This presented the highest activity of any such fragment recovered: a gamma field of 500 R/h near contact was measured. A detached flake was quantitatively analysed by gamma spectroscopy with the following results (as of March 1, 1978).

TABLE 9

Radionuclides Accompanying Flake From ML-3(10)

(Activities in microcuries per gram)

Co-58	0.3
Zr-95	30.
Nb-95	11.6
Ru-103	11.4
Ba/La-140	5.4
Ce-141	300.
Nd-147	54.

Except for Co-58, all are typical fission products. In another portion of the same sample analysis showed the presence of uranium as well. The internal structure of this fragment suggested that two or more components (including uranium fuel and steel) had been mixed by fusion.

7.3 Small Particles

7.3.1 Location

A large number of very small particles, quickly determined to represent the fuel of the reactor (presumably as foreseen by the USSR), were recovered during both the winter and summertime searches. A single particle is shown lying in snow, in relation to a Canadian 1-cent piece, in Figure 19. Particles were recovered primarily from NWT communities south of Great Slave Lake, but significant numbers were also recovered from roads, railways, cabins, lodges, etc. in the affected zone*; from areas sampled on the surface of Great Slave Lake and other lakes (before break-up); and to a much lesser degree from communities in Northern Alberta and from

* During Phase I, 42 cabins and lodges were visited by helicopter; at six of these, particles were found (nine in all); during Phase II, 130 remote sites (including many of those done under winter conditions) were visited, producing 50 particles.

FIGURE 15 Reconstruction of one end of the "stovepipe" from debris found on the snow nearby. Note the visual evidence of melting of the rim.

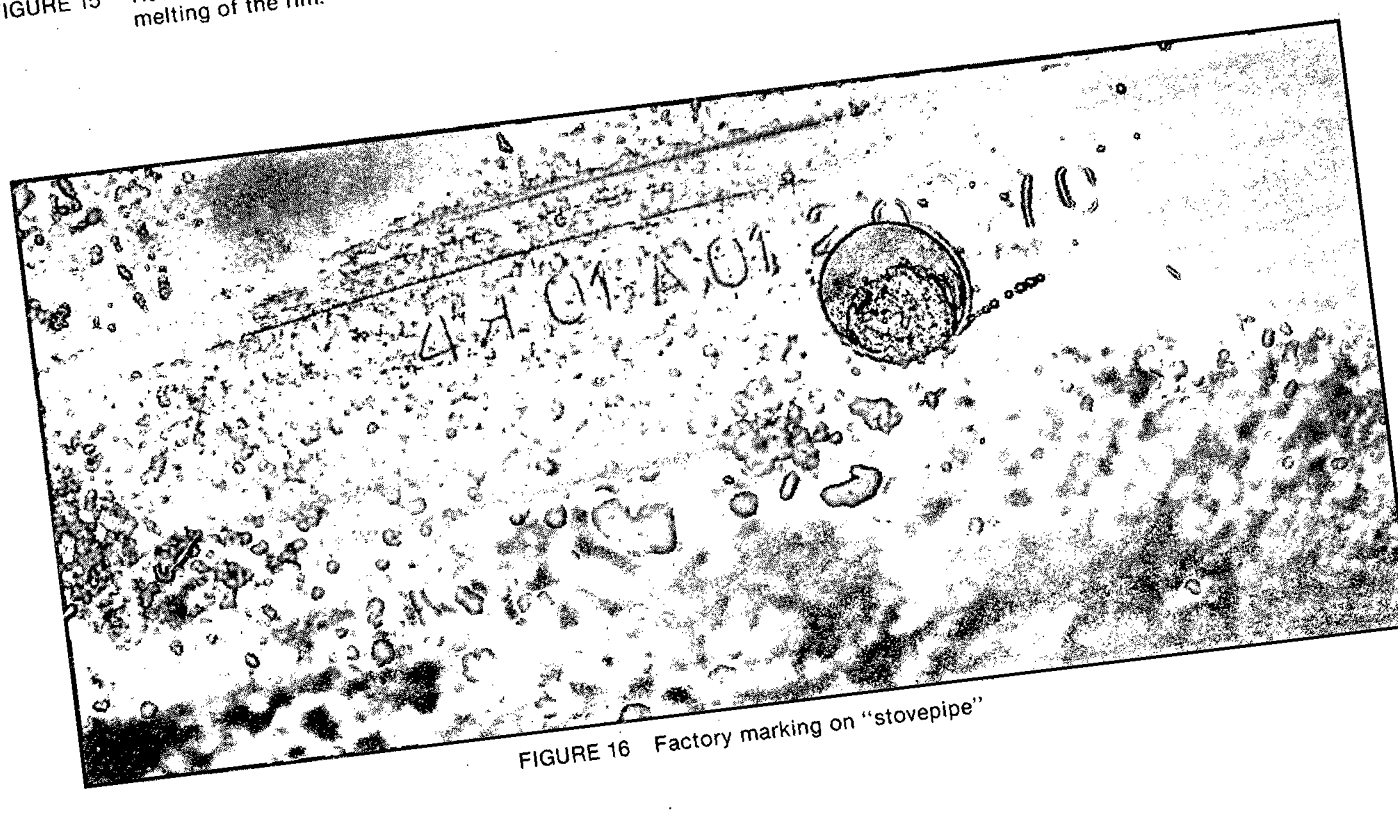

FIGURE 16 Factory marking on "stovepipe"

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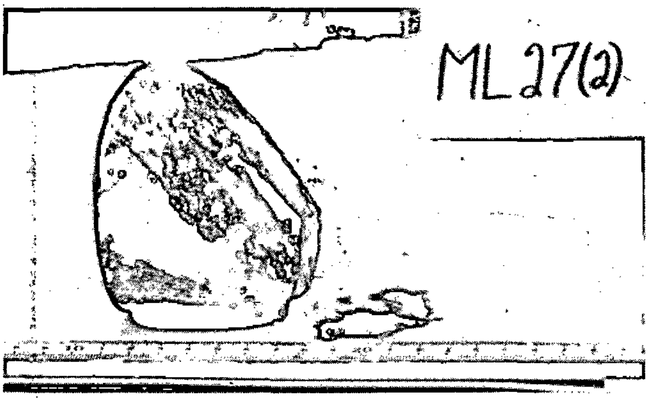

FIGURE 17 The "moose hoof", a beryllium fragment (ML-27(2)).

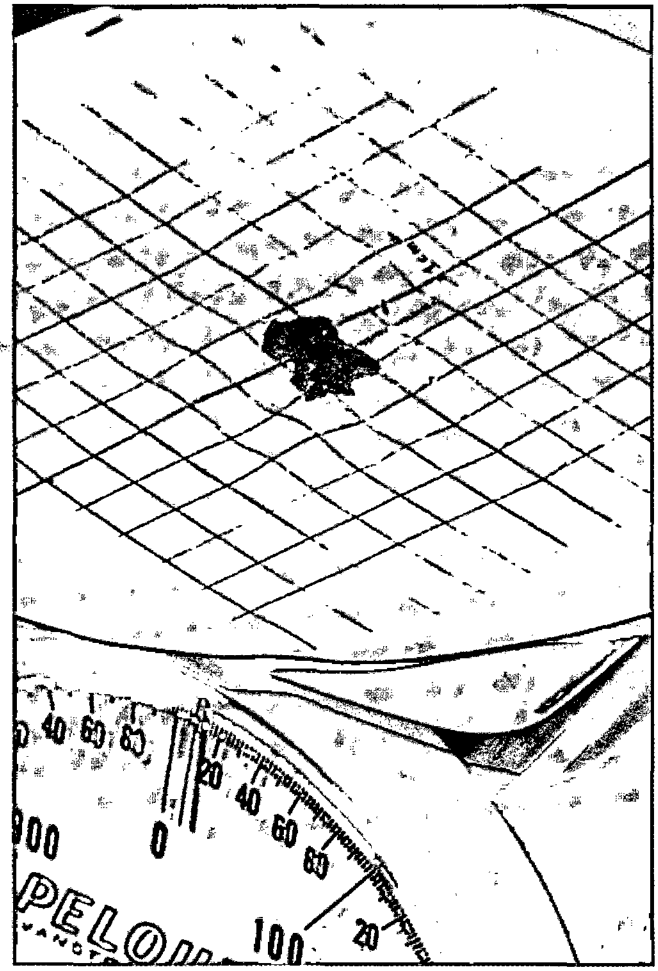

FIGURE 18 The "hottest" fragment discovered, presenting a gamma radiation field of 500 R/h near contact. The possible presence of such fragments strengthened the thoroughness of the search because of their potential hazard to life.

uranium prospecting sites in northern Alberta and Saskatchewan. These finds, along with the results of airborne gamma surveys, have indicated an extensive area over which such particles were spread (Figure 2).

The area affected by particles is in excess of 100,000 square kilometers. It is known with only some accuracy. On the western side, none were found west of Hay River, and the western part of Buffalo Lake was apparently not affected (according to the winter ice-surface survey). This defines the western side of the area rather clearly.

Snowdrift represents the eastern limit on Great Slave Lake. South of Snowdrift there are no roads for access; there are numerous lakes and rivers, and on these many cabins and lodges for hunting and fishing purposes. During both winter and summer periods, many of these were visited by helicopter and the grounds searched for debris. The map prepared by James F. MacLaren Ltd. (1) under the Phase II contract is reproduced as Figure 20, and shows particles found at sites visited between Great Slave Lake and the 60° parallel.

The southerly extension is less clear. There were sections of roads, both north and south of Fort Smith, that produced no particles while adjacent sections yielded particles. Thus the fall was not evenly distributed everywhere. No particles were found in Fond-du-Lac or Camsell Portage in Saskatchewan, although prospectors reported their occurrence west of Camsell Portage on the northwest side of Lake Athabasca (Spring Point). None were found in Embarras Portage in Alberta, but a few were located in Fort Chipewyan and as far south as latitude 58° on either side of the Saskatchewan-Alberta border.

Thus it appears that although particles were clearly carried to the south and southeast the distribution was not even. Although adjacent to Great Slave Lake all towns and roads in the zone exhibited particles, there is evidence from road surveys in which stretches with few or no particles were encountered that the fallout "fingers out" to the south. Furthermore, with distance from the presumed source over Great Slave Lake, the size of particles decreased (small particles were carried farther) so that in effect their distribution may be said also to "fade out" as they become too small to detect.

The southwest limit of the particle area is poorly known; there was no ready means for searchers to penetrate this section. The search was therefore carried no further in this direction on the basis that a) particle fall was spotty on the road north of Peace Point; b) Embarras Portage was clear of material detectable by the regular search techniques; c) Fort Chipewyan yielded few particles and they were small; and their detection required very close instrument search; d) no populated places were identified in the indicated area.

The delineation of the particle area in Figure 2 is intended to indicate that there is this general uncertainty about the southern extension. It may be that actually there are one or more tongues of fall-out, perhaps a main one, extending over Fort Chipewyan and the west side of Lake Athabasca to the Richardson River, where a few particles were found by prospectors.

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FIGURE 19 The minute size of particles is exemplified by this photograph in which a Canadian one-cent piece provides the contrast with a single particle to its right.

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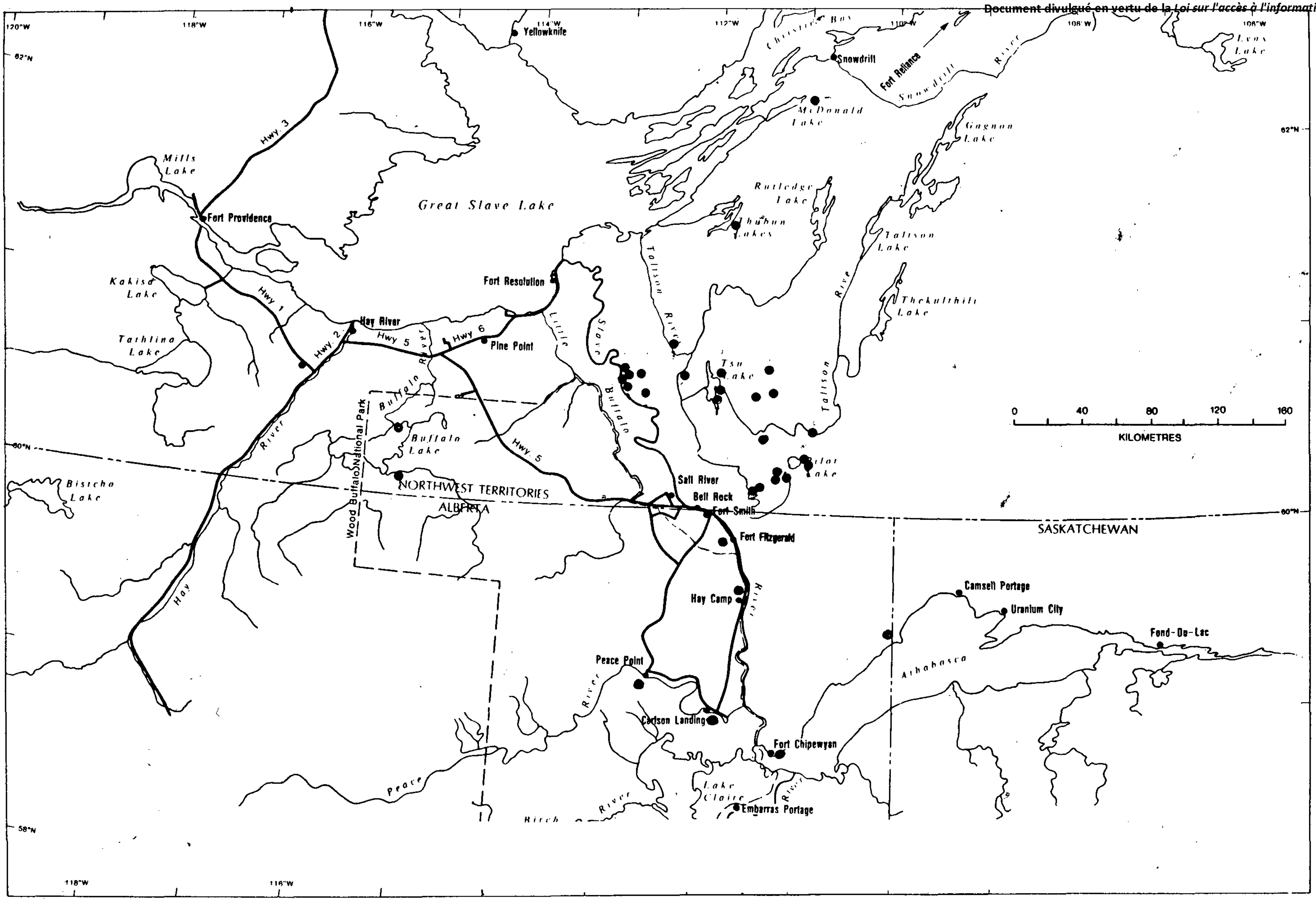

FIGURE 20 Location of particles found during ground surveys of remote sites in Phase II. Map prepared by James F. MacLaren Ltd. (reference 1).

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APPENDIX D provides a record of particles found in communities, on highways and on or around various lakes. Details of ground searches in Phase II are given in the MacLaren report (1).

7.3.2 Characteristics of Particles

General

There were two quite distinct types of particles. The dominant group consisted of small, high density spheres and accounted for by far the bulk of the particles recovered overall. These will be referred to as Category 1 particles and are easy to define. The other group, Category 2, comprises a variety of particles. Many were flaky, thin, friable, curved or twisted; others were smooth, round or oval, but low-density in comparison with Category 1 particles and somewhat larger in size at the same location. The flaky ones were easily determined in the field to be unlike the Category 1 particles, but the density distinction was only discovered by examination in the WNRE laboratories.

Of about 4000 particles recovered, approximately three hundred were individually examined at WNRE and NHW for one or more characteristics such as shape, weight, size, density, chemical composition, radionuclide content and solubility. Examples of these measurements are summarized in Tables 10,11,12,13 and 14. Almost all of these tests were carried out on particles recovered during the winter; the few analysed from the summertime recoveries yielded little new information. The results of these tests were used to help define the hazards that similar particles presented, the number of particles in a given area (and their mass and amount of activity), and the area over which such particles might have spread.

Chemical Composition

Many recovered particles were analysed by a variety of techniques to determine their chemical composition, showing the two categories to differ sharply.

A scanning electron microscope photograph of a Category 1 particle recovered from Snowdrift is shown in Figure 21. The photo on the left shows the outer surface of the particle. In the right-hand view the particle is shown to possess a crystalline outer layer, which has been analysed as uranium dioxide (UO_2) and which is clearly distinct from the substrate. Figure 22 shows a cross-section through such a particle along with elemental maps of uranium and molydenum in which the white areas indicate presence of the element being mapped. These show a high concentration of uranium and absence of molybdenum in the outer layer, consistent with its identification as UO_2. The metallic core beneath this layer is apparently made up of a variable uranium/molybdenum alloy containing 5-15% or more molybdenum (and possibly some oxygen). Dendrites of essentially pure molybdenum are visible at the centre of the particle. Their presence confirms that these particles have solidified from a uranium-molybdenum melt, indicating that they have survived a very severe thermal excursion, which has obscured their original form.

The uranium was found to be enriched to nearly 90% in U-235.

Some particles of the second category contain significant amounts of uranium (but less than Category 1), alloyed primarily with the components of stainless steel (nickel, iron, chromium, etc). In addition, significant amounts of niobium and tantalum have been detected in some particles. It was found in subsequent examination of a single spherical low-density particle, i.e. not a Category 1 particle, that no oxygen, carbon or nitrogen was combined with uranium, but that much beryllium was present.

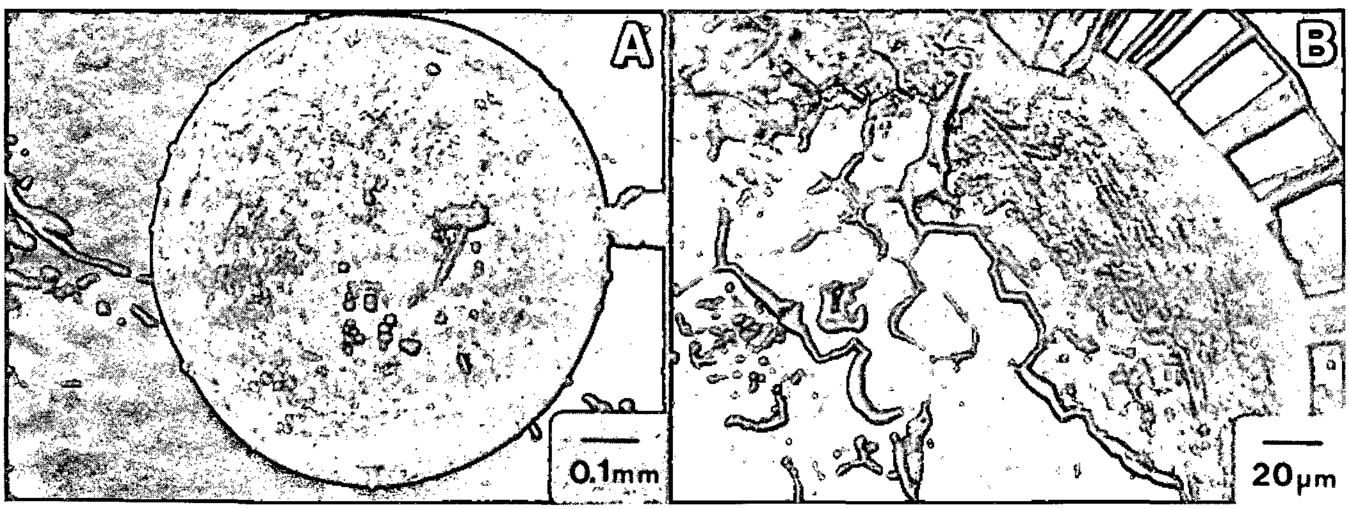

FIGURE 21 Scanning electron microscope views of a Category 1 particle. (a) shows surface texture; (b) shows that the surface represents an outer skin, apparently largely uranium dioxide.

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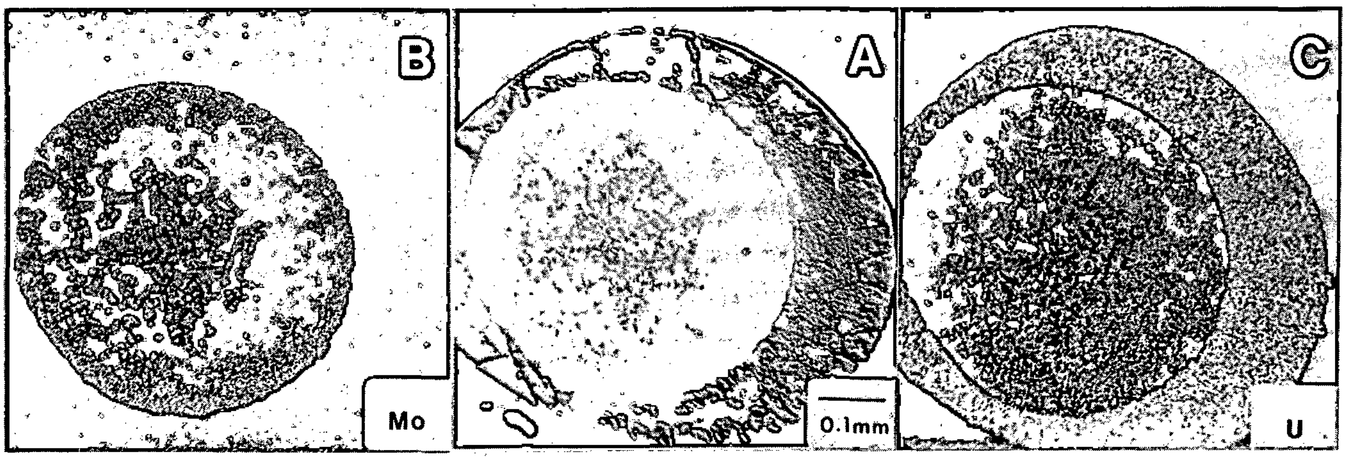

FIGURE 22 (a) is a polished section of a particle showing the core-and-rim structure; (b) shows the distribution of molybdenum (white), essentially only in the core of the particle, and (c) shows the distribution of uranium (white). These are X-ray fluorescence element maps.

TABLE 10

Average Dimensions and Activity of Particles Recovered from Various Locations

Location	Particle Category	Number of Particles Examined	Average Mass (mg)	Average Radius (mm)	Average activity (Curies/gram)	Counting date
Snowdrift area	1 (high density)	12	2.3	.380	—	—
	2 (lower density)	2	2.6	—	—	—
Pine Point area	1	2	0.145	0.145	0.8	14 March 1978
Hay River area	1	8	0.370	0.210	0.4	30 March 1978
	2	15	0.750	0.350	0.1	30 March 1978
Fort Resolution area	1	64	0.22	0.170	0.5	20 March 1978
	2	28	1.0	0.350	0.1	20 March 1978
Pilot Lake grid	1	35	0.015	not measured	0.7	9 March 1978
	2		included in above — no density measurement possible			
Rutledge Lake	1	3	0.093	0.128	0.5	8 May 1978
	2	3	0.3	0.4	0.04	8 May 1978
Tsu Lake	1	10	0.04	0.095	0.5	8 May 1978
	2	9	0.07	0.150	0.3	8 May 1978
Central Great Slave Lake	1	5	1.1	0.286	0.25	10 May 1978
	2	1	2.1	0.468	0.002	10 May 1978
Buffalo Lake	1	10	0.09	0.120	0.3	14 April 1978
	2	14	range from .1 to 21mg	—	0.1	14 April 1978
Fort Smith area	1	3	0.023	0.08	0.05	2 May 1978
	2	1	0.035	—	0.2	2 May 1978

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TABLE 11

Individual Radionuclide Activities for a Sampling of Particles

Location and counting date	Particle Identification[1]	Particle Category	Particle Mass (mg)	Specific Activity (millicuries per gram)								
				Zr-95	Nb-95	Ru-103	Ru-106	Ce-141	Ce-144	Sr-89	Sr-90	Others
Pine-Point 14 March 78	X0199-W3-1	1	0.148	170.	290.	150.	N.D.[2]	N.D.	N.D.	N.M.[3]	N.M.	N.D.
Hay River Area 30 March 78	X0046-W2-1	1	0.365	150.	230.	85.	10.	N.D.	N.D.	N.M.	N.M.	N.D.
	X0046-W2-6	2	0.598	35.	38.	6.2	N.D.	16.	13.	41.	1.3	La-140: 5.4 Co-58: 0.3
Fort Resolution 20 March 78	X0161-W1-7	1	0.188	250.	410.	190.	N.D.	N.D.	N.D.	N.M.	N.M.	N.D.
	X0161-W2-2	2	0.584	2.5	2.7	0.2	N.D.	1.6	1.1	N.M.	N.M.	La-140: 0.1
	X0161-W3-10	1	0.170	140.	240.	130.	N.D.	N.D.	N.D.	N.M.	N.M.	N.D.
	X0161-W4-1	1	0.193	135.	270.	160.	19.	N.D.	N.D.	N.M.	N.M.	N.D.
	X0161-W8-1	2	0.739	27.	35.	15.	N.D.	13.	8.1	N.M.	N.M.	Co-58:1.1
	X0048-W14	2	1.456	14.	20.	7.5	N.D.	5.4	N.D.	.05	.003	Co-58:0.8
Pilot Lake 9 May 78	X0366-W4	1	0.019	130.	260.	95.	19.	N.D.	N.D.	.007	.0004	N.D.
		1	0.024	38.	65.	22.	5.4	N.D.	N.D.	N.M.	N.M.	N.D.
Tsu Lake 8 May 78	X0304-W7	1	0.041	150.	300.	100.	27.	N.D.	N.D.	N.M.	N.M.	N.D.
	X0304-W12	2	0.089	38.	60.	60.	N.D.	27.	54.	12.	0.7	Co-58:0.2
Simpson Island 5 May 78	X0187-W3	1	0.978	90.	190.	75.	15.	N.D.	N.D.	N.M.	N.M.	N.D.
	X0187-W4	2	2.620	3.0	5.4	1.3	0.5	0.32	0.5	N.M.	N.M.	Cr-51:0.3 Co-58:0.5 Fe-59:0.02
	X0187-W5	2	2.082	2.4	4.3	1.2	0.3	0.30	0.5	.006	.0003	Co-58:0.8
Buffalo Lake 14 April 78	W15	1	0.082	54.	81.	25.	trace	N.D.	N.D.	N.M.	N.M.	N.D.
	W23	2	0.153	60.	110.	11.	N.D.	120.	110.	38.	1.2	
Fort Smith Area 2 May 78	W1	1	0.026	140.	235.	50.	8.1	N.D.	N.D.	N.M.	N.M.	N.D.
	W3	2	0.035	51.	70.	0.3	N.D.	23.	35.	N.M.	N.M.	La-140:0.01

[1] The first part of this code is the number of the seal on the shipping container; the last two terms are Whiteshell codes under which the particles were analysed.
[2] N.D. = not detected (looked for, not found)
[3] N.M. = not measured, but may or may not be present.

Density

The difference in density between the two categories was referred to in Section 7.3.2. The U/Mo spheres have densities in the range 8-18 grams per cubic centimeter averaging about 10. Because of their irregular shape the densities of the category 2 particles were much more difficult to determine. However, some of the more spherical ones were measured and showed densities in the range 2-6 g/cm^3 with an average of about 4 g/cm^3. The high density spheres comprise more than 80% of the particles studied.

Size and Weight

At any one location, the size and weight of the Category 1 spheres was remarkably uniform (Figures 23 and 24). The less regular and lower density particles found at the same location were, in general, larger (Figure 25). The most flake-like of these were often relatively quite large, measuring several millimeters on a side, but very thin. This variation is consistent with the ballistic behavior of these various shapes and densities.

The size and weight varied markedly with distance from the trajectory. As the particles formed and fell from the burning and disintegrating core, presumably at altitudes of 40-50 kilometers, they were carried southward by the wind. The larger, more streamlined and denser particles were least affected; the smaller ones were carried quite long distances from the original flight path. For Category 1 particles, the diameters range from a maximum of about 1.0 mm near the trajectory down to 0.1 mm or less in the most southerly areas; the corresponding masses range from a few milligrams down to a small fraction of a milligram. The regularity of the variation of particle size with distance from the trajectory is shown in Figure 26. This figure indicates, by extrapolation, that any particles which proceeded further south than the indicated boundary would be less than about 100 micrometers in diameter.

The masses of the Category 2 particles varied over a somewhat wider range and being so irregular in shape their sizes are difficult to characterize.

Radionuclide Content

The two categories of particles are also distinctly different in respect of their radionuclide content. As Table 11, shows, Category 1 particles contain only the fission

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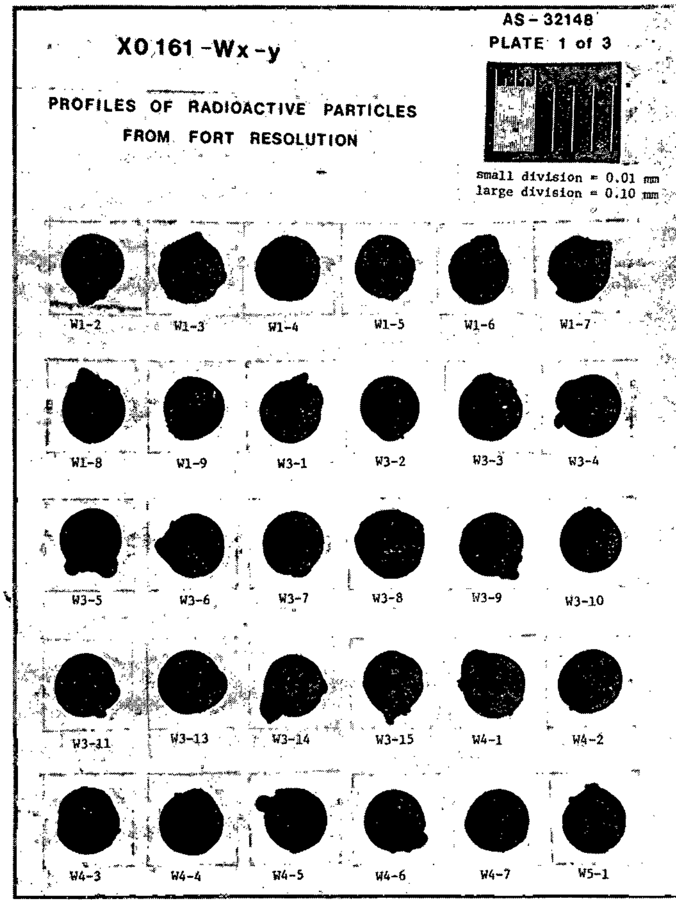

FIGURE 23 Silhouettes of Category 1 particles from Fort Resolution. W1-2, W1-3, etc., are WNRE laboratory numbers.

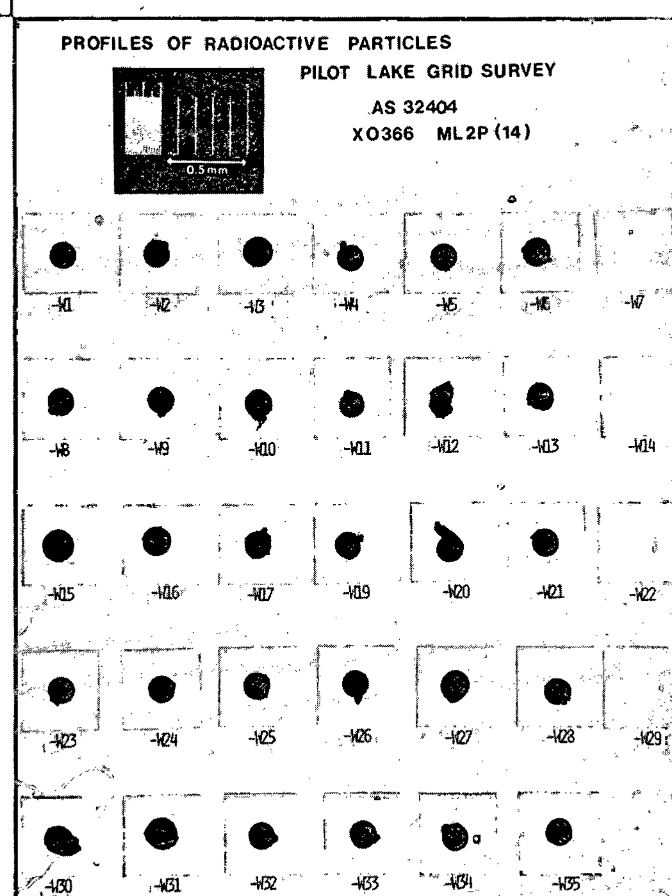

FIGURE 24 Silhouettes of Category 1 particles from the frozen surface of Pilot Lake, a short distance northeast from Fort Smith and a much longer distance south of Fort Resolution.

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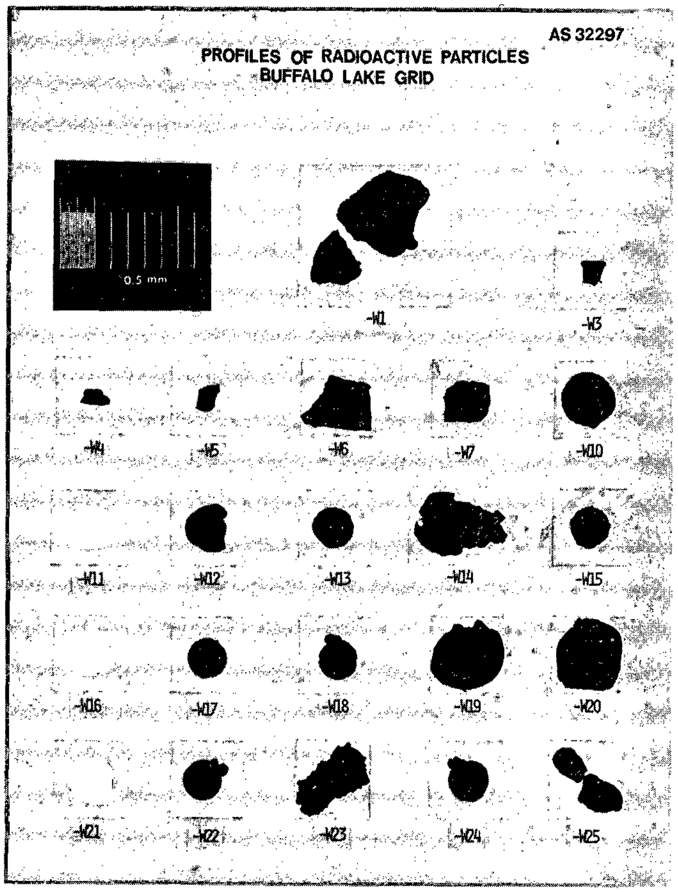

FIGURE 25 Silhouettes of particles of both categories from the frozen surface of Buffalo Lake.

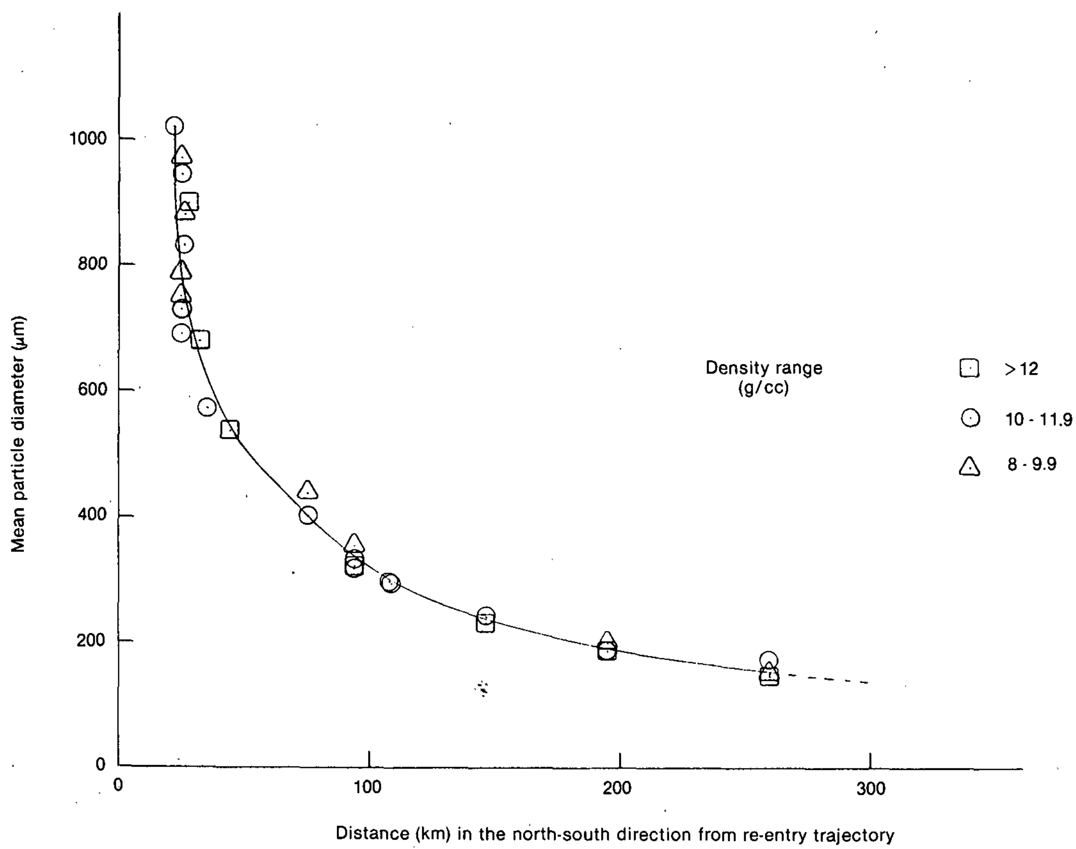

FIGURE 26 Mean particle diameter versus distance from re-entry trajectory.

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products Zr-95, Nb-95, Ru-103 and -106 at significant levels, and traces of Sr-89 and -90. Since all but the strontium are highly refractory (high melting point and low vapour pressure) elements, it would seem that the melting of this material has also driven off the bulk of the more volatile fission products such as Cs-137, Ce-141 and -144 and Sr-90.* The specific activity of these particles was apparently independent of their size and/or location. On April 1, 1978, the average specific activity was about half a curie per gram. Table 12 illustrates the rate of disintegration of radionuclides in such particles, using Zr-95 and Ru-103 as examples. Sr-90 data are also included for contrast — this isotope has a half-life of 29 years and the data show its much slower rate of decay; they also show that rather little Sr-90 was encountered on the ground. It can be noted that Zr-95 and Ru-103 (along with Nb-95, which is both a fission product and a daughter of Zr-95) are the source of most of the gamma radiation in Cosmos particles.

Category 2 particles contained a much wider variety of radionuclides. In addition to the Category 1 fission products they contained Ce-141 and -144 in large amounts, more significant amounts of Sr-89 and -90 and a variety of activation products of stainless steel: Cr-51, Mn-54, Co-58 and -60 and Fe-59. Ta-182 was also detected in some samples. Table 11 shows that the specific activity of these particles was about a factor of 5 less than that of Category 1 particles.

During the summer Phase, field measurements of size and radioactivity level confirmed the relation between and the decrease in both parameters as distance south of the trajectory increased (Table 13). Many tiny particles in Fort Smith in the summer were indiscernible against background at 1 meter, so by themselves had very low readings — less than about 5 μR/h. APPENDIX D provides data on many particles, and the following data illustrate the variation in radioactivity level in over 3000 particles recovered from the main communities during Phase II. The values are all given in μR/h at 1 meter, and the reader should realize that the exposure rate at 1 cm is about 10,000 times larger in each case. Below background, 200 particles; up to 10 μR/h, 989; 11-20, 1226; 21-30, 495; 31-40, 94; 41-50, 19; 51-60, 12; 61-70, 2; 71-80, 2; 81-90, 0; and 91-100 μR/h, 1. There were also flaky particles at 150 (2 particles) and 225 μR/h at 1 meter (1 particle).

Solubility

In order to assess the hazard that these particles presented to humans and the environment, a number of representative particles were subjected by both WNRE and RPB to solubility measurements in hot and cold water and in simulated stomach acids. Table 14 presents data from these tests.

These solubility tests have shown that, for the most part, the particles are of very low solubility. The Category 1 particles can be described as virtually insoluble. A few of the Category 2 particles, however, did display slight solubility in simulated stomach acids (about 1% dissolved in biologically relevant dissolution times). A single sample was found to be fairly readily soluble (up to 30%) in hydrochloric acid. This result represents one large, fragile flake, and may possibly not indicate true solubility but rather a suspension of fine particulates broken away from the major piece. Nevertheless, its biological effect may not be very different from that of a soluble particle. Fortunately, this type of particle was not common and could be no more than a few percent of all particles.

TABLE 12

Activities of some Fission Products at Different Dates

(millicuries per gram of as-recovered particle)

Isotopes	24 Jan '78	1 Apr. '78	1 Aug. '78	June '79	June '80	June '83
Zr-95 (64 d)	400	200	55	8	0.17	$2x10^{-6}$
Ru-103 (39.4d)	400	120	14	.6	.001	$5x10^{-11}$
Sr-90 (29 yrs)	.5	.5	.49	.49	.47	.44

Note: Zr-95 and Ru-103 are major contributors in Category 1 particles. The data for these two for 1 April, 1978 are averages of WNRE data on over 100 such particles on or about that date; figures for other dates are calculated from the appropriate half-lives. The Sr-90 values come from the average of all measurements on particles of both categories.

TABLE 13

Variation in Diameter and Radioactivity* of Particles, with Distance South of Trajectory

Location	Diameter of Particles	Radioactivity (μR/h at 1 meter)
Snowdrift	1.1 mm	30
Hay River	0.7	19
Fort Smith	0.4	10
Fort Chipewyan	0.4	less than background

*Meter readings — uncorrected for background

8. Source Term Estimates

The "source term" is defined as the inventory of both radioactive and toxic materials contained in the satellite at the time of re-entry. Clearly, to evaluate and deal with the hazard posed by Cosmos 954, a reasonable assessment of this inventory is needed. However, because the launching nation provided little detailed

* As Table 10 shows, the strontium is present at very much lower levels than the zirconium-95, etc. Because it is a beta-emitter, strontium was analysed for by a different technique. Thus, it was detected at levels at which other gamma-emitting radionuclides would not be noticed.

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TABLE 14

Solubility of Recovered Particles (Selected Data)

Particle Identification	Particle Category	Measuring Laboratories	Test Conditions	Time (Hours)	Range of Solubilities of Individual Radionuclides (%)	
					Most Soluble	Least Soluble
Ft. Resolution X0161-W6-2 (Phase I)	1	RPB	Hydrochloric Acid pH of 1 @ 22°C	17	2.3×10^{-2} (Ru-103)	4.0×10^{-4} (Nb-95)
				154	2.9×10^{-2} (Ru-103)	7.0×10^{-4} (Nb-95)
				605	6.6×10^{2} (Ru-103)	2.3×10^{-3} (Nb-95)
Ft. Resolution X0161-W3-11 (Phase I)	1	RPB	Distilled water 22°C	23	5.0×10^{-4} (Nb-95)	1.0×10^{-5} (Zr-95)
				305.	2.0×10^{-3} (Nb-95)	2.0×10^{-5} (Zr-95)
Ft. Resolution X0161-W8-3 (Phase I)	1	RPB	Distilled water 100°C	47	6.0×10^{-5} (Ru-106)	9.0×10^{-6} (Zr-95)
				355	2.0×10^{-4} (Ru-106)	4.0×10^{-5} (Zr-95)
Ft. Resolution X0161-W8-16 (Phase I)	1	RPB	Melted Snow from NWT 22°C	19	7.0×10^{-5} (Ru-103)	not detectable (Zr-95, Nb-95)
				109	6.0×10^{-4} (Ru-106)	2.0×10^{-4} (Zr-95, Nb-95)
Hay River Cs-13-G-16 (Phase II)	2	RPB	Hydrochloric acid pH 1 @ 22°C	6	4.5×10^{-3} (Ce-144)	2.1×10^{-4} (Zr-95)
				72	1.1×10^{-2} (Ce-144)	1.1×10^{-3} (Zr-95)
				240	2.2×10^{-2} (Ce-144)	3.6×10^{-3} (Nb-95)
Hay River Cs-13-G-50 (Phase II)	2	RPB	Hydrochloric acid pH 1 @ 22°C	6	6.1×10^{-4} (Ce-141)	2.1×10^{-4} (Zr-95)
				72	4.3×10^{-3} (Zr-95)	7.1×10^{-4} (Ce-141)
				240	1.6×10^{-2} (Zr-95)	2.4×10^{-3} (Ce-141)
Hay River Cs-13-G-11 (Phase II)	2	RPB	Hydrochloric acid pH 1 @ 22°C	6	1.4×10^{-1} (Ru-103 and -106)	1.8×10^{-3} (Nb-95)
				240	1.5 (Ru-106)	1.2×10^{-2} (Zr-95)
Hay River X0046-W4-1 (Phase I)	2	RPB	Hydrochloric acid pH 1 @ 22°C	5	1.6 (Zr-95)	0.2 (Ru-103)
				45	2.6 (Zr-95)	0.2 (Ru-103)
				188	3.0 (Zr-95)	0.3 (Ru-103)
Rutledge Lake W-2 (Phase I)	2	RPB	Distilled water 22°C	5	nothing detectable	—
				25	nothing detectable	—
				187	4.7×10^{-3} (Nb-95, Zr-95)	nothing detectable
Pine Point Cs-13-G-341) (Phase II)	2	RPB	Hydrochloric acid pH 1 @ 22°C	17	29.5 (Ru-103)	4.0 (Ce-141)
				143	30.9 (Ru-103)	4.3 (Ce-141)
Ft. Resolution X0161-W8-7 (Phase I)	2	WNRE	Distilled water @ 22°C	7.5	2.6×10^{-3} (Nb-95)	ND (Zr-95)
				584	1.6×10^{-1} (Nb-95)	3.8×10^{-2} (Zr-95)
Ft. Resolution X0161-W3-7 (Phase I)	1	WNRE	Distilled water @ 100°C	7.5	5.5×10^{-4} (Nb-95)	nothing else detected
				584	1.2×10^{-1} (Nb-95)	2.2×10^{-2} (Zr-95)

information about the satellite and its design, the "source term" can only be estimated. While rough estimates of the inventory of fission products have been derived, nothing can be concluded with respect to the total amount of activation products (and toxic materials) except by inference from materials recovered.

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In the first attempts to estimate the fission product inventory of Cosmos 954, calculations were based on the design features of an early Russian space reactor, Romashka, of which some details were published in the open literature in 1964 (8).

However, recovered debris soon showed that the reactor on Cosmos 954 was not similar to the Romashka design. Since a knowledge of the power level is necessary in order to calculate the total fission product inventory, considerable effort was expended to arrive at an independent means of estimating it. The only information available that could provide a lead in that direction was the concentration of fission products contained in recovered fuel particles. If plutonium (Pu) were present, as an activation product from neutron capture by U-238, its concentration would also be useful, and a single determination was therefore carried out.

The number of fission events per unit weight of fuel was calculated on the basis of the following information and assumptions:

i) The Pu-239 content in the core at re-entry was assumed to be $5.9 \pm 0.6 \times 10^{-6}$ grams per gram of uranium. (This value was obtained from the single plutonium analysis of one fuel fragment).
ii) The average Zr-95 specific activity in recovered fuel fragments was approximately 0.1 Ci/g on April 1, 1978; for Ru-103 the corresponding value was 0.05 Ci/g. These values are rough averages from several hundred fuel fragments.
iii) The average uranium content of fuel particles was of the order of 80% and this was enriched to nearly 90% in U-235. These results were averaged from a number of determinations.
iv) Recovered fuel particles were assumed to be representative of the original intact core.
v) The Cosmos 954 reactor was assumed to have a fast neutron spectrum. This is consistent with some of the activation product yields and is implied in Russian comments. An average neutron energy of 1 MeV was assumed for determination of the absorption and fission cross-sections of U-238 and U-235.
vi) The reactor was assumed to have operated continuously from launch to re-entry, i.e. 128 days.

Calculations based on the above yield the following results for the three species referred to:

i) from Pu-239 — 1.6×10^{18} fissions/gram of uranium
ii) from Zr-95 — 2.1×10^{18} fissions/gram of uranium
iii) from Ru-103 — 2.9×10^{18} fissions/gram of uranium

Taking the average value for burn-up as 2×10^{18} fissions per gram of uranium, a specific power of approximately 5 W/g of uranium was derived. A minimum fuel mass can be estimated from consideration of the amount needed to achieve criticality. For a fast reactor with a thick beryllium reflector and high uranium density, a critical fuel mass of at least 18 kg of highly enriched uranium is indicated. Assuming a value of 20 kg, the power for Cosmos 954 would be of the order of 100 kW, and, using an existing computer program (FISSPROD) at AECL's Chalk River laboratories, the fission product activity at shutdown was calculated to be about 500,000 curies. These calculations are not without considerable uncertainty; however, this is the best estimate that has yet been derived. The fission product inventory and its decay with time is shown in Figure 27. Note that the initial decay rate is extremely rapid, because many of the fission products have short half-lives. After one year, according to this curve, only one two-hundred-and-fiftieth (1/250) of the original inventory exists, after two years about one seven-hundredth.

The inventory of *activation* products is unknown since neither the mass of structural material nor the neutron flux to which it was exposed can be determined. However, it can be stated with near certainty that it will be but a small fraction of the fission product inventory.

9. The Question of Unrecovered Material

9.1 General

The description and characterization of recovered material in Section 7 allows the nature of the hazards posed by the debris from Cosmos 954 to be described. However, the degree of the hazard (the "risk") must be evaluated on the basis of the amount of similar material which remains in the environment. With completion of the search and recovery program, a major objective has been to provide an estimate of the amount of unrecovered material.

The inventory of hazardous material on board at re-entry has been defined as best as possible in Section 8, but the assessment of risk is complicated because there is no way of knowing at the present time how much material was "burned up" during re-entry and remains suspended in the upper atmosphere in the form of minutely divided "dust" particles. Therefore, the best estimate of the amount of radioactive material which reached the ground can be gained by extrapolation from what was recovered.

9.2 Larger Fragments

The foregoing limitations apply especially to any attempt to estimate the number and activity of larger fragments which remain undetected. These larger fragments would be predominantly associated with the structure, rather than the core, of the nuclear reactor, with much of their activity arising from the decay of activation products. Obviously little can be said of what

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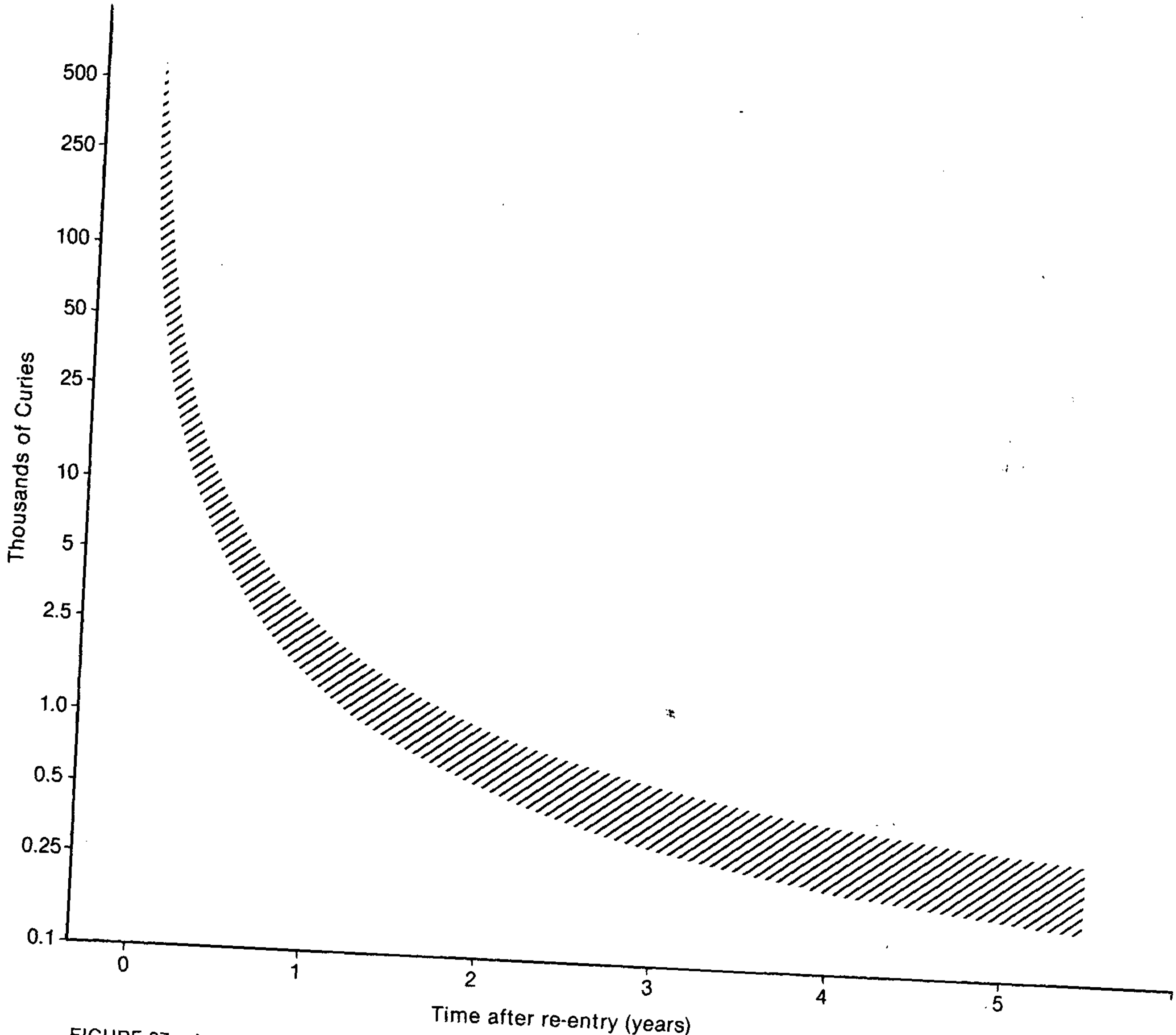

FIGURE 27 Approximate range of fission product activity from Cosmos 954 debris, and its decay with time.

was initially present let alone what might have reached the ground.

Another approach is to consider what might have been missed by the search technique. The probability of detecting a radioactive fragment using an air-borne gamma search technique is a function of a large number of parameters including detector characteristics, air-frame speed and altitude, spacing of flight lines, snow and ice cover, atmospheric conditions, background radiation, operator skill and, of course, the activity level of the fragment. It has been determined that for the wintertime search conditions and the C-130 search parameters, the most highly active fragment which would have been missed, if all conditions conspired against detection, would be of the order of 150 mCi (i.e. one which would exhibit an exposure rate of about 300 mR/h at a distance of one meter). On the other hand, fragments with exposure rates down to about 10 mR/h at one meter were detected during that phase of the search; this can perhaps be regarded as a lower detectability limit under favourable conditions. The exact relationship between activity and probability of detection between these limits would be very difficult to derive. However, it is known that the relationship is not linear; the detection probability increases rapidly as the activity increases above the lower limit such that objects midway between the limits discussed would have a detection probability well in excess of fifty percent.

As an additional aid to interpreting what the search may have missed, parts of the area were subjected to the closer scrutiny of helicopter-borne equipment (detection sensitivity increased over that of a Hercules by a factor of about four). For example, during the winter an area about 9 km by 8 km, spanning the trajectory just east of Artillery Lake, produced no "hits" in the original search by Hercules although it was considered on the

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basis of ballistic calculations to be a prime area for larger objects; likewise none were found in a subsequent helicopter re-survey.

On the other hand, another search along two flight lines passing through the area where the largest number of fragments had been recovered turned up two additional beryllium cylinders. During the summer, searches by a detector-equipped helicopter and DC-3 in the area where the bulk of the beryllium rods had been found in the winter recovered ten new "hits" including seven additional rods.

In the light of this somewhat conflicting information, statements with regard to the amount of material left in the environment must be cautious ones. It is almost certain that all fragments with activities greater than 150 mCi would have been found during the wintertime search, but it must be admitted that few fragments of less than about 5 mCi (as of the search date) would have been "spotted" from C-130s. However, reflights of selected areas do indicate that there can not be large numbers of large fragments still lying about.

Confirmatory information provided by the USSR is of interest in this discussion. When advised of the recovery of the beryllium fragments, the USSR stated that of six moving elements in the satellite's beryllium reflector all had been found, and that of several tens of beryllium rods most had been found. Since at that time only 34 had been recovered, with the final total at 41 it may be presumed that few are unaccounted for if indeed they landed.

At time of publication of this report, all unrecovered objects will have decayed to a few percent of the activity existing during the 1978 wintertime search; the vast majority will be much less than 1 mCi. Further, after break-up in the spring of 1978 any unrecovered fragments lying on ice would have sunk to the bottom of lakes and rivers, where they would present a much reduced environmental hazard.

9.3 Small Particles

Estimates of the amount and distribution of unrecovered fuel particles from the reactor core are somewhat better defined than those for large objects. It should be borne in mind that the approach to the clean-up of the two-classes of debris was fundamentally different. For the larger fragments, the goal was removal of all highly radioactive material from the environment; for the fuel particles (once it had been concluded that no major portions of the reactor core had survived intact) the goal was to remove them from inhabited and frequented areas. Since these areas form only a small part of the total area affected, most of the core material which reached the ground remains in the general environment. Its possible behaviour there will be considered later.

On the assumption that the core consisted of about 20 kilograms of U-235, and reactor power of the order of 100 kW, as of 1 April, 1978 the total fission product inventory would have been of the order of 13,000 Ci. Not all of this material and its associated activity reached the ground, however. High altitude air sampling carried out by the Environmental Measurements Laboratories (9) of the U.S. Department of Energy in June and September, 1978 over Alaska confirmed the presence of significant concentrations of 90%-enriched U-235 in the upper atmosphere between 30 and 40 kilometer altitude. Their conclusion is that this material is from Cosmos 954. No estimate of the amount of material so suspended has been made since the volume of atmosphere so affected is not known. However, the results are compatible with a significant fraction of the Cosmos 954 core having remained air-borne. More thorough sampling was carried out in the spring of 1979 by which time the material had descended to altitudes attainable by aircraft, however, results were not available at time of writing. The indication is that Cosmos 954 products are now mixed with material from atomic bomb testing. Suspended core material will eventually settle on the ground but over a very large area (similar to the fallout from weapons testing), and one which may of course be remote from the Great Slave Lake area.

These considerations alone then, do not lead to a reliable estimate of how much fuel material and its associated activity reached the earth's surface following reentry. However, two other techniques were applied to provide an improved estimate of the total mass and activity of Cosmos 954 fuel that actually reached the ground within this area.

The first of these techniques, devised by GSC (4), surveyed the total activity (in excess of background) deposited on the ice of Great Slave Lake, where interference from natural radiation from rock could be avoided. A detector-equipped helicopter flew a total of thirteen traverse lines, providing systematic coverage of the lake area (see Figure 28). Integration of the results over the entire lake surface then provided a measure of the total excess activity present as of 1 April 1978. This survey provides quite a clear picture of the distribution of activity over the lake surface prior to 1978 spring break-up. Most of the contamination was concentrated in the middle of the lake, with the eastern, northern and western reaches essentially uncontaminated. The activity fell off rapidly towards the southern shore line. The land profile insert in figure 28 highlights a significant fact: the average *natural* background activity over the uncontaminated land mass was higher than that over even the most contaminated part of Great Slave Lake. The survey also confirmed a conclusion derived from analyses of individual particles; the preponderant activity was from Zr-95, Nb-95, Ru-103 and Ru-106. The more volatile fission products such as cesium-137 and

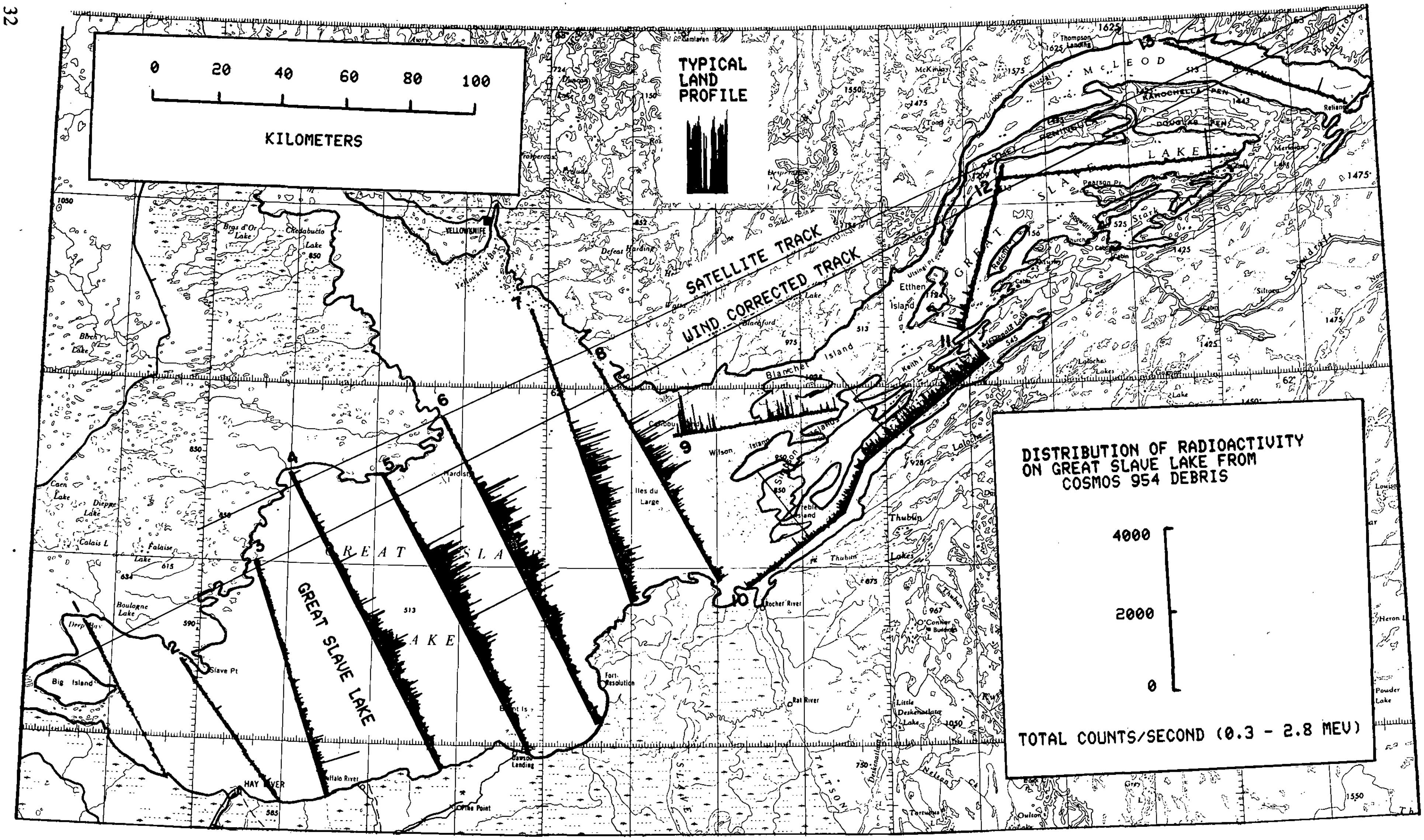

FIGURE 28. Distribution of radioactivity over frozen Great Slave Lake as of 1 April, 1978. Note that as traverse lines near the south shore the level of radioactivity decreases.

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iodine-131 were not detected nor were the many activation products which had been seen in some recovered particles.

The integration of the information from this aerial survey yields a total of approximately 700 curies of mixed fission product activity on the surface of Great Slave Lake as of April 1, 1978.

To extend this sort of information over a large portion of the estimated dispersion area, a plan was evolved by the U.S. Department of Energy to sample a number of selected frozen lakes, recovering and examining the number and characteristics of all radioactive particles within a standardized sampling grid.

Particles recovered during the sampling surveys were carefully analyzed at WNRE and the results provided much information on the variation of properties among the various classes of particles, and on particle size variation from location to location. However, the results of total mass and/or activity per unit area deduced from each sampling are so scattered that this approach was not further pursued. The wide variation probably reflects markedly uneven distribution of particles, just as found in road searches in particular, and perhaps also incomplete recovery in sampling areas. Nevertheless, the results do support the indication of a decrease in activity per unit area towards the south from a maximum in the middle of Great Slave Lake. A rough estimate of the total activity over the entire dispersion area would be of the order of 2,500 curies (as of April 1, 1978), which is compatible with the 700 curies on the lake surface alone. This represents about 20% of the calculated total inventory of the satellite at that date. The corresponding fuel mass associated with this activity would be around 4 kilograms.

As with the larger fragments, estimates of the activity remaining on the ground must allow for radioactive decay; as of January 1979 the 2500 curies would have been reduced to about 300 curies. Also it was shown that the most highly contaminated area was central Great Slave Lake. When the ice melted, all of this material would have sunk to the bottom to become incorporated in sediments.

The balance of the "source term", decayed to about 1000 curies of mixed fission products, after a year and a half, is concluded to have been trapped in the upper atmosphere. Its return to earth will be gradual and very widespread with a risk level which is very small compared to that of nuclear weapons fallout.

10. Risks to People and the General Environment

10.1 General

Fragments of significant size fell in a well-defined belt, and there is reasonable assurance that not much was missed. If there is a remaining hazard from other large fragments, it lies in that limited area and has been minimized by careful search and recovery. The particles, on the other hand, fell in great numbers over a wide and incompletely delineated area, and it is these in particular that must be considered in a review of overall environmental concerns. Again, it is the fission products that have been of concern, and have raised questions about environmental contamination with respect to fauna and flora. Due to the short life-time of the reactor, activation products, whose chief hazard would have been by external radiation if living organisms remained close to them for an extended time period, did not become a major problem.

In considering the behaviour of particles in the general environment, there are several features to be considered: their abundance; their shape, size and density which will affect their physical behaviour in water and soils; their toughness (or in some types their friability), which will affect the length of time they continue to exist as such; their solubility; and of course their content of fission products. Considering the last first, as Table 2 shows, most of the fission products possess short half-lives. The species of major concern are Sr-90 and Cs-137 with half-lives of about 30 years; these can accumulate in key tissues of living organisms (including people) — skeleton for strontium and muscles for cesium. These are among the radioisotopes that have been extensively monitored for a number of years, in connection with nuclear weapons testing, so that a data base exists for comparison with Cosmos 954 fall-out.

It has been calculated, using AECL's FISSPROD program (see Section 8) that there might have been about 50 curies each of Sr-90 and Cs-137 at the time of re-entry. If all of this activity had come to earth, by comparison with recorded fall-out records it is estimated that the total deposition per unit area would have been about one fourteenth of the amount received in the Yellowknife area in 1973 from weapons testing fall-out; that year was the *lowest* measured in 20 years of monitoring. In fact, analytical data indicate little Sr-90 and less Cs-137 in Cosmos 954 material — it is evident that only a small fraction came to earth, so that the impact on the environment of the unrecovered particles is likely to be insignificant when compared with the fall-out deposition that exists currently. Most of these two isotopes were dispersed in the upper atmosphere along with the volatile species such as iodine and noble gases, and they will contribute a trivial increment to the present inventory of such substances in the stratosphere.

Particles that fell on frozen bodies of water would eventually enter the water and settle to the bottom where, in the normal course of events, they would sooner or later become incorporated into sediments and from that point on be progressively more and more isolated from food chains. In loosely consolidated sedi-

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mentary material of similar size distribution most would tend to sink because of their high density, and their smooth spherical habit.

In vegetation on land, as snow melted and runoff proceeded during and following spring break-up in 1978, the fallen particles would soon work their way downwards becoming part of the existing mineral or organic base materials.

Townsites and frequented places were scoured to find and remove the particles; during the winter, the areas to be frequented during the 1978 Winter Games were given special attention. Particle searches were not carried out in bush, tundra, and generally unfrequented areas. It would clearly be impracticable to attempt in such areas the type of search that was made in townsites and on roads. The particles assumed to have fallen over some 100,000 square kilometers of such land and water surface must be left to be absorbed into the natural domain by settling, and long drawn-out dissolution, accompanied by radioactive decay.

There are several other encouraging features to be borne in mind when considering residual hazards from unrecovered particles. Particles will not readily become resuspended (a necessity for inhalation) under normal circumstances. Most of them were largely insoluble in simulated stomach acids, and it was demonstrated that they are still less soluble in natural water; thus movement of constituents in such waters will be limited. Most of the radionuclides present have short half-lives, so that a year after date of fall only a small fraction of their original radioactivity would have remained. The longer-lived radionuclides (particularly Sr-90 and Cs-137) are present, but in very small accounts.

It was also encouraging to the searching personnel to learn during the Phase II community searches that the areas accessible to winter search could be identified by the much reduced incidence of particles, although some additional finds were made in such searched areas (for instance in locations where snow had been piled up by ploughing).

10.2 People

In summary, the potential risks to people included external radiation to part or all of the body, and internal radiation by inhalation or ingestion.

The concern about whole body irradiation was rather soon dispelled when it became clear that the reactor core had not survived more or less intact, and that sufficiently large pieces of other radioactive material were not likely to exist. Irradiation of a significant part of the body was quite possible to persons remaining in the vicinity of significant fragments. The continued close control by health physics staff prevented exposure to search personnel. Efforts were made by the RCMP, and by officials of the NWT government and of INA, to warn trappers and hunters to avoid the vicinity of any unusual object, and requesting immediate advice of its existence. There were no confirmed reports of such finds. At time of writing, residual hazards of this nature are considered negligible.

Control over the risk of internal radiation was less possible. Ingestion was always a hazard as a result of using contaminated melted snow for cooking or drinking purposes, in spite of public cautioning against the practice in the area of concern. It was calculated that if an average particle were ingested, say in early to mid-1978, it would be capable of giving a radiation dose, mainly to the lower large intestine, roughly equivalent to that of a conventional X-ray of the gastric area. This organ would in most cases be the one affected because most particles would be essentially insoluble during passage (48 hours or less) through the body. Specific internal doses would actually be reduced if more soluble material were ingested, because soluble material would be transported to other organs in the body as well.

In this connection, water supplies from community reservoirs along the south shore of Great Slave Lake were found by RPB to show no radioactive contamination during the search periods. A further series of analyses will be carried out in 1980 of water supplies to see if any unexpected radioactivity appears.

Inhalation was improbable in Phase I since particles fell in snow and were unlikely to rise to be swept into nose or mouth. With break-up, thawing and runoff, particles would have been still less accessible to inhalation. There would have been a relation between size and potential dose — larger particles would be capable of presenting a higher dose but with little likelihood of being available for inhalation; smaller particles, with somewhat more chance of being inhaled, would present relatively inconsequential doses.

From the first stage of Phase I, all those likely to be exposed — field staff, storage crew, even air crew — carried devices to record their exposures, if any. A summary of all records is given in APPENDIX F. The total number of persons covered was 353, including all Canadian personnel and the U.S. NEST staff, and some of these were involved in both Phase I and II. Of these, 145 received a measurable dose, but the highest individual accumulated whole-body dose was 470 mrem (and so was the highest recorded skin dose), far below the maximum permissible doses for atomic radiation workers — 5000 mrem per year for whole body, 30000 mrem per year for skin.

Finally, it is worth mentioning that the winter explorers who coincidentally came upon the "antlers" on the Thelon River were quickly given a clean bill of health by medical authorities after examination.

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10.3 The General Environment

The logic applied to humans is considered to apply equally to wildlife, with respect to contact with and ingestion of debris. Unless a particle became lodged in the digestive system it would be passed in a time period that kept exposures below a hazardous level.

With respect to vegetation, wildlife personnel were at once concerned with the question of contamination of moss, on which caribou, for instance, sustain themselves essentially year round. A study carried out at the University of Toronto (10) produced evidence that moss in the debris area did not pick up radioactive contamination in the usual sense of fall-out, i.e. as very finely divided matter from air-borne vaporized fission products. Moss collected south of Great Slave Lake (and also north of the trajectory zone) led the authors of this study to conclude that fission products detected on moss samples do not exceed background levels found in the general area due to past nuclear explosion fall-out.

RPB has carried out analysis of caribou meat taken during the fall (1978) hunting season (11). These analyses showed no indication of contamination by Cosmos 954; the Sr-90 and Cs-137 levels were lower than in results obtained from meat several years previously. Samples of rain and snow from the national precipitation network, including stations in the area, were examined for gamma and gross beta radiation; RPB was unable to relate results to Cosmos 954.

The question of contamination of fish, which are so important to the region in commercial and sport fisheries and as a local source of food, has been covered by special studies at the Freshwater Institute (of DFE) in Winnipeg. In analysis of meat from 10 species of fish (592 fish taken in April, 1978, and 687 in September, 1978) fisheries experts have "not detected radionuclides derived from Cosmos 954" (12). Cs-137 alone of those to be expected from Cosmos debris was present, but at activities to be expected from global fall-out of thermonuclear bombs exploded mainly in 1959-64.

Realizing the probable spread of particles into that area, concern was raised about the breeding sites of the endangered whooping cranes in Wood Buffalo National Park. The matter was discussed with Canadian Wildlife Service personnel in Edmonton, and it was agreed to fly over nesting sites and to examine selected ground (frozen swamp) areas. This was done by a special helicopter flight with CWS personnel present. Low level flights over nesting sites did not detect any radiation. One pond in the area was surveyed on foot and no particles were found. Surveying was kept to this minimum since break-up was approaching and the cranes would soon be returning; avoiding fright to the returning birds, and damage to nests, was of paramount importance. The conclusion was that there would not be enough radioactivity from debris to cause harm to the whooping cranes by exposure, and that any particles present would settle into bottom mud and rapidly become inaccessible for ingestion.

Thus the question of environmental harm to the area affected by Cosmos 954 debris appears to be answered rather convincingly. The effects of the debris on any identified or observed part of the natural environment are considered to be insignificant.

11. Concluding Statements

Except for those tiny particles that drifted southwards, all debris fell on Great Slave Lake and on unpopulated and little frequented areas to the northeast. There is reasonable assurance that all accessible significantly-sized radioactive fragments were located and removed. Six beryllium cylinders were found; the USSR has stated that there were no more. Forty-one beryllium rods were found and the USSR said that most (of "several tens") had been found. Several were partly consumed during re-entry, thus it is possible that some never reached the earth's surface.

Debris of the order of 65 kg weight has been recovered. Of this, about 18 kg is represented by the non-radioactive "stovepipe", leaving some 47 kg of radioactive material. Almost all of this is accounted for by the "antlers", the beryllium artifacts, and pieces of steel. The proportion represented by tiny particles is minute — the 4000-odd that were recovered would weigh less than 5 grams.

The inventory of radioactivity indicates that perhaps 20% (4 kg) of the fuel came to earth. This would mean that the 4000 recovered particles represent about 0.1% of the possible total, and that the bulk of the 4 kg remained uncollected when Phase II was stopped.

Various estimates were made from actual particle recovery in specific sections of the area that indicate that the distribution of particles may be as high as several hundred per square kilometre. This is highly variable, since distribution has been shown to be uneven. Two hundred and fifty per square kilometre is equivalent to one particle every 4000 square metres.

Granted that such figures can only be approximate, they do place some perspective on such statements as the claim quoted in the press that the ground was left "littered" with radioactive particles. They also support the belief that much remains in the upper atmosphere as a result of the burn-up that indeed the USSR expected. This is presumably where the bulk of the more volatile fission products rest; they were not found on land. It appears likely that most of the strontium and cesium fission products are also still in the upper atmosphere. After nearly two years, because of atmospheric movements and mixing since re-entry, it will not be possible

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to identify these particular isotopes in the upper atmosphere or in fall-out with any assurance that they relate to Cosmos 954. The key to the existence of Cosmos 954 dust in the upper atmosphere is the presence of 90% enriched U-235, as found by balloon sampling in 1978(9).

In the early stages of the search and recovery operations it was impossible to claim that dangerously high radiation might not exist on large fragments not yet found, or that all of the particles were likely to be as small and relatively low in radiation level as was eventually learned. The finding of the fragment ML-3(10), with a radiation field of 500 R/h near contact, meant that search operations could not be carried out half-heartedly nor allowed to come to a stop until a measure of assurance was achieved that all possible such fragments had been located and recovered.

Search and recovery did go on until this assurance was gained and it was possible to conclude that: (1) it was most unlikely that additional fragments such as ML-3(10) could have been missed; (2) all obvious fragments had been located; (3) that although particles could indeed present a risk to people, a sufficient number had been examined to show that the risk was not great because of their size, insolubility and scattered distribution; (4) particles had been adequately recovered from frequented places; and (5) residual radiological risks from material left on the ground were fading so rapidly relative to natural background that following the cessation of Phase II no harm to people and the environment could be foreseen. On this basis, a calculated decision was made to discontinue search and recovery operations in October 1978.

It is important to realize that these statements can only be made because of the extent of the search and recovery operations, and of the thorough analysis and research that were carried out on recovered debris. This report has not been concerned with the costs of the operations, but it is mentioned here that the total cost to the Canadian Government in reaching the position from which the above statement can be made came to nearly $14,000,000.

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Appendix A

Chronology

The following dates delineate the major features of the development and extent of the search and recovery operations for Cosmos-954 remnants.

18 September, 1977	— launching of Cosmos 954
19 January, 1978	— U.S. government advises all nations potentially involved of the coming re-entry
23 January	— the AECB first learned of the possibility of re-entry over Canada, through advice from senior government officials and DND
24 January	— re-entry occurred at 0653 hours (EST) over the Queen Charlotte Islands off the British Columbia coast; glowing remnants reported over Great Slave Lake area by eye-witnesses
	— DND Nuclear Accident Support Team members from Edmonton at once went to Yellowknife to check the townsite for radiation
	— AECB advised Geological Survey of Canada (GSC) of the event and the probable need for air-borne detection assistance; GSC expert reached Edmonton
	— U.S. gamma radiation equipment and NEST personnel reached Edmonton in the evening
	— list of technical questions on nature of satellite prepared by AECB and submitted to USSR Ambassador
25 January	— first Canadian Forces Hercules air-borne with US search equipment
	— GSC equipment to Edmonton and put into operation
	— high level air sampling by U-2 and KC135 planes from US
26 January	— First AECB team (5 men) arrived in Edmonton
27 January	— first air detection of radioactivity from a fragment on Great Slave Lake near mouth of Hoarfrost River, 27 km. north of Fort Reliance
	— GSC equipment was already in use aboard a Canadian Forces Hercules aircraft. Eleven Canadian craft were in the air, and one US plane with infrared equipment
28 January	— an object (to become known as the "antlers") was coincidentally located near Warden's Grove on the Thelon River by naturalists wintering in the area. This was the farthest east find; it was also the largest remnant located
31 January	— AECB removes first piece of debris ML-5(1)
	— visual sighting and recovery of a fragment on ice of Great Slave Lake — this was the non-radioactive "stovepipe", ML-10(1)
5 February	— 250 Canadian Forces personnel and 115 US personnel were now involved. GSC and AECB personnel reached 13 and 11 respectively
7 February	— base camp established near Warden's Grove, on Thelon River, for further search in the eastern end of the landing path
8 February	— official Canadian advice through the Department of External Affairs to USSR that fragments of Cosmos 954 had been found
12 February	— first report of particles in vicinity of Snowdrift.
14 February	— detailed survey of people and houses in Snowdrift following discovery of small particles of residual core material
24 February	— most radioactive fragment, ML-3(10) picked up following its discovery on 20 February. Gamma radiation field of 500 R/h on contact.
10 March	— report from Cape Dorset, Baffin Island, of unexplained occurrence of large blocks of ice on a frozen lake, on the

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	extension of the fall-out path from Great Slave Lake
15 March	— Microwave Ranging System interfaced with GSC detection equipment
20 March	— report that there was no sign or evidence of satellite action at Cape Dorset; ice phenomenon was natural
10 April	— total flying time reached 4635 hours
18 April	— last search flights before break-up covered settlements and cabins between Fort Smith and Hay River
20 April	— Phase I shutdown
24, 25 May	— public meetings in Snowdrift, Fort Resolution, Pine Point, Hay River and Fort Providence for discussion of search program and of risks to people. Involved representatives of AECB and NHW as well as NWT and local officials.
6 July	— public meeting in Uranium City, Sask., to provide information on particles and the risk they present.
10 July	— AECB opened office in Hay River for coordination of Phase II operations
18 July	— Contractor staff began arriving in Hay river; ground survey commenced in NWT towns, roads, camps, lodges, etc.
12 September	— Search for particles extended into northern Saskatchewan and Alberta
14 October	— operations of Phase II completed

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Appendix B

Health Physics Aspects

1. Biological Effects of Radiation

Man and his environment have been exposed to ionizing radiation from natural sources since time began. However, it was not recognized that radiation could have any detrimental effect until the actual discovery of X-rays and radioactivity at the turn of the century. With increased experience, there was a growing awareness of the health hazard presented by excessive radiation exposure, an awareness stimulated by unfortunate high exposures such as those experienced by early radiologists and the radium dial painters of the 1920's. Since then radiobiology and radiation medicine have developed into major sciences which study both detrimental and therapeutic aspects of radiation.

Biological damage is a result of the ionization of atoms or molecules, a process which will disrupt cell structures or contents. This may lead to the immediate death of the cell, the inability of the cell to perform its function, or genetic damage to the cell's chromosomes causing the ultimate death of the cell or altered characteristics being "passed on" to its offspring.

The seriousness of a radiation exposure is determined by the number of cells affected and their importance to body function and reproduction. Different types of body cells or tissues vary in their radiosensitivity; muscle and central nervous system cells are relatively insensitive whereas the blood-forming and the reproductive organs are highly sensitive. Similarly, doses received by extremities are not as serious as the same dose received by such organs as the gonads, the lungs or the gastrointestinal system.

Radiation exposures are characterized by the rate at which they are received. Acute exposures are those received over a short period of time (hours or less). Exposures spread over long periods (up to a lifetime) are termed chronic. If an acute exposure is high enough, some effects may be observed; those that develop in the body of the exposed individual are termed "somatic", those that appear in subsequent offspring are termed "genetic" effects. Short-term somatic effects may be observed following an acute exposure. Externally noticeable symptoms are not apparent at doses less than 100 rem, but about one half of those exposed to 450 rem will die within 6 weeks of exposure. There are also delayed effects from both acute and chronic exposure. The most frequently observed delayed somatic effect is cancer, which may not be observed until many years after exposure. There may also be delayed genetic effects which are passed on to the succeeding generations by an increase in the natural mutation rates; these defects include deformities, susceptibility to disease, and premature death.

Cell damage is not irreversible. Regeneration or renewal of cellular structure can occur if the cell is not severely damaged. Also cells that are killed outright may be replaced by other healthy cells.

Although some controversy still persists and the relationship is not without exceptions, it is generally accepted that there is a linear relationship between absorbed dose, i.e. the energy deposited per unit mass of tissue, and the biological effect. Because this implies that any increment of radiation exposure carries with it an incremental risk, it is recommended that radiation doses be kept as low as reasonably achievable.

Dose limits applying to man-made sources of radiation in Canada are prescribed by the Atomic Energy Control Regulations (13); they do not apply to natural background or to medical exposures.

2. Types of Radiation

The four types of radiation, which might all have been encountered from Cosmos 954 debris, are as follows:

Alpha radiation: Alpha radiation is made up of relatively heavy, charged particles and, as a result, does not penetrate far in matter; in fact the range of alpha radiation in air is only a few centimetres, and it can be stopped by a single sheet of paper. As a result, alpha rays do not present any hazard while they are outside the body, but if a source of alpha rays gets inside the body, it may become more serious.

Alpha radiation is generally associated with the more massive radionuclides; the uranium that constitutes the fuel of a nuclear reactor is a weak alpha emitter.

Beta radiation: Beta radiation is also made up of charged particles, but they are very much lighter than alpha particles and have more penetrating power. The range of beta rays in air depends upon their energy but is generally measured in meters for those that are associated with fission and activation products; however, a thin sheet of aluminum or plastic, or a thin layer of water or ice, will stop these rays.

Beta radiation, due to its somewhat limited penetrating power, is of greatest concern when a radiation source is in contact with or very close to the outside of the body (in which case it will deposit most energy in the tissues closest to the surface), or when the radiation source is inside the body (in which case most energy is deposited within the organ where the radionuclides are concentrated).

Gamma radiation: Gamma radiation can be thought of as electromagnetic waves similar to X-rays; conse-

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quently, gamma radiation is much more penetrating than either alpha or beta radiation, and can travel much further. Because of its greater penetrating power, gamma is generally the most important radiation when considering the exposure of people by sources that are outside their bodies. The absorption of gamma radiation is also different from that of alpha and beta radiation; to reduce the intensity requires increasingly thicker absorbers. Typical absorbers are steel, lead and concrete, although water, in sufficiently thick layers, also makes a good shield.

Neutrons: Neutrons are produced by the fission process itself. Neutrons are also particles but carry no electric charge so that they can penetrate matter readily. They are primarily an external hazard. (Early in the Cosmos 954 search neutrons were of concern due to the possibility of discovering a major portion of the core that might still have been critical and hence producing neutrons. As already described, it became clear that the core had not survived re-entry intact, and neutrons were not detected at any time during the search.)

3. Health Physics

3.1 Radiation Protection Principles

"Health physics" comprises the body of knowledge dealing with the effects of radiation on man and his environment, and places particular emphasis on practical means for protecting both from harmful effects.

Since there is some degree of risk in all radiation, the International Commission on Radiological Protection (ICRP) has recommended that all radiation exposures from man-made sources should be justified and kept *a*s *l*ow *a*s *r*easonably *a*chievable (the "ALARA" principle, usually with the qualifying phrase "economic and social conditions being taken into account"). In keeping with this principle, there are three key steps that can be taken:

i) keep the *time* of exposure as short as possible;
ii) kept at a safe *distance* from the source;
iii) introduce some suitable *shielding* material between oneself and the source.

The matter of keeping at a safe distance requires further consideration. Exposure rates are governed by the "Inverse Square Law"; for instance, if the exposure rate at 10 centimeters is 200 R/h, then at 100 centimeters the rate is reduced not by a factor of 10 but by the square of 10, or 100, and would be 2 R/h. The effect, of course, works in reverse and the exposure rate increases very rapidly as one moves closer to the source.

3.2 Definition of Measurements of Radiation

Rate measurements — Rate measurements give an instantaneous indication of the intensity of a radioactive source or a radiation exposure field. (Such a measurement is similar to that made by the speedometer in a car which indicates the rate at which the car is moving.)

Integrated measurements — Integrated measurements give the amount of radiation exposure accumulated over a definite period of time. (An integrating instrument is analogous to the odometer in a car which tells how many kilometers or miles have been driven.)

Contamination measurements — Contamination measurements are made directly and indirectly. Generally, direct measurements on samples of snow, water, and so on must be made in a laboratory in order to obtain meaningful results, but direct measurements on surfaces can be made in the field using specially designed contamination meters. Indirect measurements are made to find out how easily surface contamination can be transferred. A piece of paper wiped over the contaminated surface is checked and if no radioactivity is detected on the piece of paper, it indicates that any contamination that may exist will not be removed easily.

3.3 Estimation of Radiation Doses

Radiation doses may be external or internal.

For estimating *external* dose, due to radiation sources outside the body, those at risk are provided with an integrating device or *dosimeter* that responds to the radiation energy deposited in it. The most commonly used dosimeters during the clean-up program were the "film badge" (the degree of darkening of the film on developing can be calibrated against known exposures), and the quartz fibre electroscope, which can be read directly by the person using it. The dosimeter should respond to the radiation of interest in a manner similar to that of human tissue, and the irradiation conditions should be reasonably uniform. Under ideal conditions, it is possible to obtain good results, but under field conditions, it is often difficult to obtain accuracies better than 50%.

An alternative to the integrating device is to take the exposure rate measured with a suitable radiation survey meter and multiply it by the length of time the person has been exposed at that rate. This technique is most useful in predicting the dose that may be received in the performance of a certain operation.

An *internal* dose cannot be measured directly. By measuring the rate of elimination from the body of the radionuclide of interest, and by having knowledge of the metabolism, and the radioactive characteristics of the particular radionuclide, it is possible to formulate a mathematical model of the radionuclide's behaviour inside the body, from which the internal dose can be calculated.

It is not always possible to make measurements on the people concerned; then it is necessary to make measure-

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ments on the radioactive material itself, from which, knowing the material and its solubility, the dose resulting from ingestion of an assumed quantity can be calculated.

3.4 Methods of Calculating Internal Doses

Small particles that are *swallowed* will follow one of two possible routes, as shown in Figure 29, depending upon whether the material is classed as transportable or non-transportable — terms used by ICRP to described the ease with which different materials can transfer across body membranes.

In simple terms, if the material is classed as non-transportable it will simply pass through the gastrointestinal tract and be excreted from the body. If it is classed as transportable, some fraction of it will transfer from the small intestine to the body fluids, whence it can be deposited in other organs of the body; the remaining fraction behaves as non-transportable material.

The radiation dose received by any of the body organs depends upon a number of factors: the fraction of the ingested radioactivity that reaches a particular organ, the effective half-life of the radioactivity in the organ (the "effective half-life" combines the effects of radioactive decay and biological clearance from the organ), the effective energy deposited in the organ as a result of the radioactivity, and the mass of the organ (14, 15, 16).

The organ that receives the highest fraction of its maximum permissible dose is called the critical organ for ingestion of a particular form of radioactivity. For many radionuclides, the critical organ is the lower large intestine for ingestion of both soluble and insoluble material.

The mathematical model for calculating the dose to parts of the gastrointestinal tract is different from that for the other organs mainly because of the short residence time in each section (17).

In contrast to the ingestion situation, particles *inhaled* by nose or mouth will follow paths outlined in Figure 30. Part of the material inhaled will be deposited in the respiratory tract and the remainder will be exhaled. The respiratory tract is divided into three regions, the nasopharynx (N-P), the tracheo-bronchial (T-B) and the pulmonary (P) regions. The division of the inhaled material between these three regions depends upon the size and mass of the particles; large particles will be deposited mainly in the N-P region and smaller particles mainly in the P and T-B regions. The material is either cleared from these three regions through the blood and thence to other organs in the body, or is expelled by muco-ciliary action to the gastrointestinal tract; the route taken and speed of clearance are determined largely by the solubility or transportability of the material. The dose to the various organs, including the respiratory tract, can be calculated if the time-integral of the radioactivity in the particular organ, the energy deposited, and the mass of the organ are all known. Generally, in cases of inhaled radioactivity, if the material is classed as insoluble, non-transportable and strongly retained, the critical organ is the respiratory tract; if the material is classed as soluble, transportable and minimally retained, the choice of critical organ is more varied than for the case of ingestion of the same material, and could include bone, liver, kidney, spleen, lower large intestine, and total body.

The mathematical model for calculating dose to the respiratory tract (18, 19) assumes biological decay of a dispersed source of dust particles, whereas the concern caused by Cosmos 954 is with single particles which are either present or not present in the respiratory tract. This difficulty has been overcome by assuming that an inhaled particle resides in a particular region of the respiratory tract for a period of time equal to the mean biological life.

4. Calculated Doses and Discussion of their Significance

The most important radionuclides found in association with radioactive debris are listed in Table 15 together with the calculated dose to the critical organs

TABLE 15

Calculated Internal Dose Resulting from Intake of One Microcurie

Radioisotope	*Dose to Lower Large Intestine for Unit Activity Ingested, mrem/μCi	**Dose to Nasopharynx Region for Unit Activity Inhaled mrem/μCi
Chromium-51	1.7	10
Manganese-54	22.8	171
Iron-59	50.0	310
Cobalt-58	29.5	215
Cobalt-60	77.3	534
Strontium-89	95.0	407
Strontium-90	36.9	817
Zirconium-95	41.6	385
Niobium-95	27.4	192
Ruthenium-103	24.1	199
Ruthenium-106	228.0	1,039
Cesium-137	59.8	304
Barium-140	52.6	1,023
Lanthanum-140	84.3	726
Cerium-141	29.1	133
Cerium-144	227.8	964
Tantalum-182	66.3	415
Uranium-234	84.4	36,390
Uranium-235	91.4	66,160
Plutonium-239	91.4	39,350

* Calculated according to model of Dolphin and Eves (17) using numbers given by ICRP (14,15,16).
**Calculated according to the model given by ICRP (18) modified as described in text, section 3.4 above.

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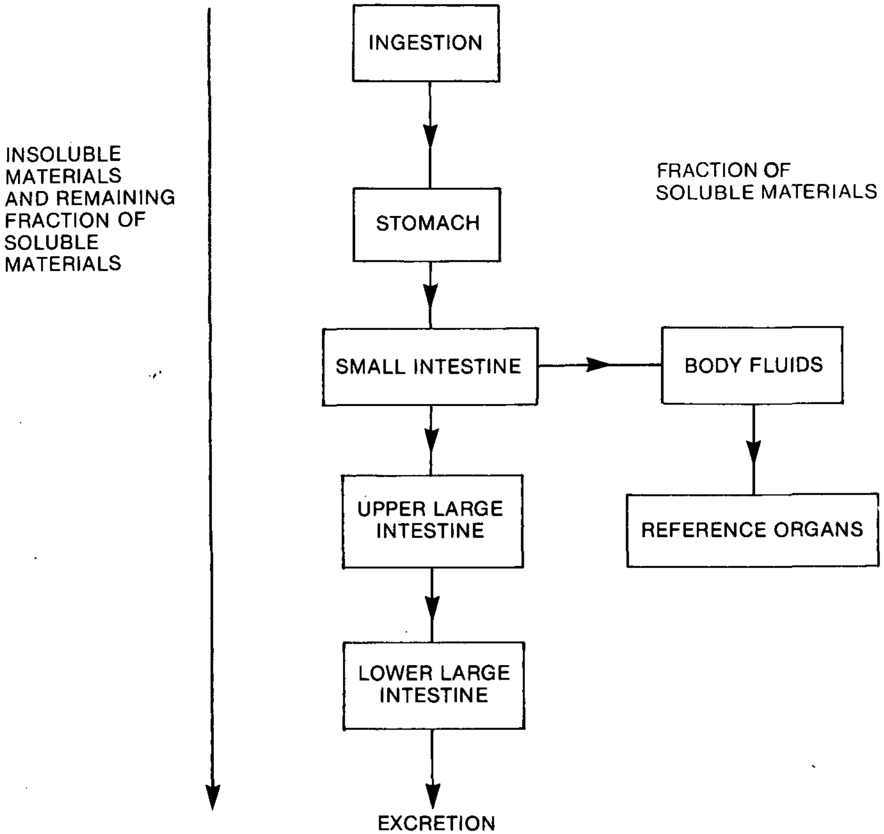

FIGURE 29. Simplified model of paths followed by ingested materials.

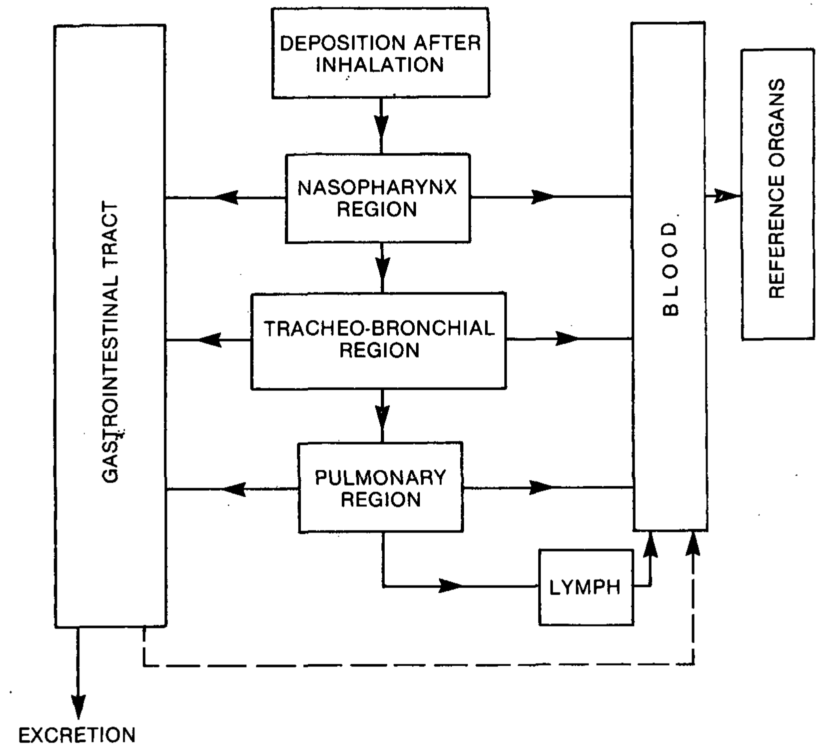

FIGURE 30. Simplified model of paths followed by inhaled materials.

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that would result from ingestion or inhalation of one microcurie.

In order to calculate the dose due to swallowing or breathing in a real particle, it is necessary to take account of the relative radioactivity of different radioisotopes. If this is done, it will be found that there was potential for high doses, near the time of impact, which could have been many times the maximum permissible dose for atomic radiation workers; this potential dose is reduced as the radioactivity decays with time.

These doses have been labelled as potential, because if a realistic mechanism of intake to the body does not exist there is little chance of actually receiving such doses. In the case of intake by ingestion, the generally low solubility limits the movement of the radioactivity in the environment and there is little likelihood of intake by the common routes in drinking water and food. In the case of inhalation, at the large size/weight end of the range of particles the potential dose is high, but the likelihood is very low of the particle becoming suspended in the air at breathing level and, with a high settling velocity, the chance of intake is also very low. As one approaches the lower end of the size/weight range, the chances of resuspension and intake increase, but the potential doses would be much smaller.

5. Non-radioactive Toxic Materials

In addition to the hazard of radiation, the presence of beryllium was of concern; beryllium is a highly toxic element, and extra care was needed both in the field and in laboratory operations to avoid contamination. A serious contamination of WNRE's hot cell facility (not of people) by dust from sawing a beryllium cylinder required painstaking clean-up.

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Appendix C

Portable Field Instruments

Table 16 summarizes the nature and application of the various portable field instruments employed at one time or another in the search and recovery operations.

Most instruments are designed for operation over a reasonable range of environmental conditions, but the extreme cold experienced in the Northwest Territories during the months of January, February and March posed a severe test of all instruments. All field instruments were of necessity powered by batteries. The extreme cold shortened battery-life in most cases to such an extent that it was essential to keep batteries warm by either holding the whole instrument inside one's parka between uses, or removing the batteries and keeping them in a warm pocket until required again — some instruments had the advantage of having a separate power supply unit which could be kept warm inside clothing while only the detector and meter needed to be exposed to the low temperatures. Since it was necessary to wear heavy mittens, any delicate adjustments of instruments were difficult out-of-doors.

During search operations, instruments with an audible output were useful since visual observations were often very difficult under the weather conditions existing.

Instruments with co-axial cables also presented a problem if the cable was permitted to get too cold, and the low humidity resulted in spurious readings due to static electricity.

TABLE 16

Principal Instruments Used in Field

Specific application	Name or type of instrument and model number	Detector*	Range of readout	Manufacturer or supplier
Search and recovery. Phase I only	Low range gamma survey meter. Model PRM-4	Scintillator 1" x 1" NaI cylinder	0–5,000 μR/h	Eberline
Search and recovery. Phases I and II	Low range gamma survey meter. Model PRM-7	Scintillator 1" x 1" NaI cylinder	0–5,000 μR/h	Eberline
Search and recovery. Phase I and II	Low range gamma survey meter. Model 19	Scintillator 1" x 1" NaI cylinder	0–5,000 μR/h	Ludlum
Search and recovery. Phases I and II	Model SPP 2NF scintillometer	Scintillator 1" x 1 1/2" NaI. Variable threshold	0–15,000 CPS	Saphymo-Stel
Search and recovery. Phase II only	Low range gamma survey meter. Model TC-33A	Scintillator 1 1/2" x 1 1/2" NaI cylinder	0–5,000 μR/h	McPhar
Field assessment of hazard. Phases I and II	Wide range beta/gamma survey. Model PIC-6	Ionization chamber with beta window.	0.2 mR/h - 1,000 R/h	Eberline
Field assessment of hazard. Phase I only	Gamma survey meter. Model 5016C	Two geigers	0.2 mR/h - 10R/h	Canadian-Admiral
Field assessment of hazard. Phases I and II	Beta/Gamma survey meter. Model LB-1200	Geiger with beta window.	1 μR/h - 100 mR/h	Berthold
Field assessment of hazard. Phases I and II	Teletector multi-range gamma survey meter. Model 6112	Geiger with telescopic probe	100 μR/h - 1,000 R/h	Eberline
Field assessment of hazard. Phases I and II	Contamination meter. Model E-140	Pancake geiger. Model HP-260 for surface contamination measurements. Model HP-210 with SH-4 shield for swipes and air filter counting		Eberline
Field assessment of hazard. Phases I and II	Mini-scaler Model PS-2-2	Pancake geiger Model HP-210 with SH-4 shield.		Eberline
Field assessment of hazard. Phases I and II	Personal air sampler. Model Siersat. Whatman 41 filter papers			Nuclear Associates

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Field assessment of hazard. Phases I and II	Alpha/gamma counter. Model PAC-1SAGA	Geiger for gamma 59 cm^2 ZnS sheet scintillator for alpha.	Gamma: 0-2 R/h Alpha: 0-2,000,000 CPM.	Eberline
Field assessment of hazard. Phase I only	Portable gamma spectrometers.	Scintillator, NaI Solid state, Ge-Li.		Supplied by US NEST
Field assessment of hazard. Phase II only	Pulse height analyser system. Model TN-1706	Scintillator. 2" x 2" NaI in 2" lead shield.		Tracer-Northern

*Dimension in inches are as given by supplier.

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Appendix D

TABLE 17

Summary of Fragments Recovered

Hit No. (Note 1)	Position (Note 2)	Date & Means of Discovery	Physical Description	Gamma Radiation Field* (Note 3)	Date of Recovery
ML-1(1)	WE 764 679	High altitude search 27/1/78	Charred metal piece approx. 225mm x 75mm x 6.5mm	Up to 200 R/h near contact	4/2/78
ML-2(1)	WE 948 803	MRS 5/2/78	Charred metal rod approx. 100mm long x 20 mm diam.	30 R/h contact 150 mR/h at 1 m	15/2/78
ML-5(1)	WE 746 717	Ground search 30/1/78	Rod similar to ML-2(1)	10 R/h near contact 150 mR/hr at 1 m	31/1/78
ML-6(1)	WE 959 809	High altitude search 30/1/78	Rod similar to ML-2(1)	25 R/h contact 100 mR/h at 1 m	10/2/78
ML-10(1)	WE 678 715	Visual from air 31/1/78	Hollow cylinder approx. 500mm long x 360mm diameter and 12 fragments various sizes	Not radioactive	31/1/78
ML-11(1)	WE 946 818	Ground search 1/2/78	Rod similar to ML-2(1)	2 R/h contact	2/2/78
ML-12(1)	XE 006 765	Helicopter search 2/2/78	Piece of ribbed sheathing, approx. 60mm long and 40mm wide	30 R/h contact	3/2/78
ML-13(1)	WE 816 740	MRS 5/2/78	Rod similar to ML-2(1)	100 mR/h at 1 m	20/2/78
ML-15(1)	WE 683 667	MRS 8/2/78	Rod similar to ML-2(1)	600 mR/h contact 10 mR/h at 1 m	4/3/78
ML-16(1)	WE 745 718	MRS 7/2/78	3 small flakes in cluster	100 mR/h at 1 m for the cluster	20/2/78
ML-19(1)	WE 874 766	MRS 5/2/78	Rod similar to ML-2(1)	10 R/h contact 125 mR/h at 1 m	26/2/78
ML-20(1)	WE 881 778	MRS 5/2/78	Rod similar to ML-2(1)	80 R/h contact 200 mR/h at 1 m	26/2/78
ML-22(1)	WE 503 539	MRS 16/2/78	Flake, black, size of a potato chip, approx 25mm long	10 R/h contact	18/2/78
ML-23(1)	WE 250 488	MRS 16/2/78	Rod similar to ML-2(1)	6 R/h contact 100 mR/h at 1 m	2/3/78
ML-24(1)	WE 183 424	MRS 16/2/78	Part of rod similar to ML-2(1) 50mm long	10 R/h contact	18/2/78
ML-32(1)	XE 033 849	Helicopter search 21/3/78	Rod similar to ML-2(1)		5/4/78
ML-33(1)	WE 495 585	Helicopter search 23/3/78	Metal fragment approx. 75mm x 25mm x 3mm	100 mR/h at 1 m	24/3/78
ML-35(1)	WE 900 784	Air search July 1978	Rod similar to ML-2(1)	2 R/h (and 4 rad/h) near contact; 100 mR/h at 30 cm	July 1978
ML-36(1)	WE 965 815	Air search July 1978	Rod similar to ML-2(1)	20 R/h (and 100 rad/h) near contact; 70 mR/h (and 100 mrad/h) at 1 m	July 1978 (Note 4)
ML-37(1)	WE 956 787	Air search August 1978	Rod similar to ML-2(1)	30 mR/h (and 100 mrad/h) at 1 m	August 1978
ML-38(1)	WE 968 791	Air search August 1978	Rod similar to ML-2(1)	9 R/h (and 10 rad/h) near contact; 70 mR/h (and 150 mrad/h) at 30 cm	August 1978
ML-39(1)	WE 904 845	Air search August 1978	Rod similar to ML-2(1)	20 R/h (and 20 rad/h) near contact; 500 mR/h (and 1.3 rad/h) at 30 cm	August 1978

*All readings are meter readings uncorrected for background.

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Summary of Fragments Recovered (cont'd)

Hit No. (Note 1)	Position (Note 2)	Date & Means of Discovery	Physical Description	Gamma Radiation Field* (Note 3)	Date of Recovery
ML-40(1)	WE 940 718	Air search August 1978	Small metallic flakes; 20 mm x 10 mm, and 10 mm x 5 mm		August 1978
ML-41(1)	WE 410 557	Air search August 1978	Rod similar to ML-2(1)	3-4 R/h near contact Small area also contaminated	August 1978
ML-2(2)	XE 154 906	MRS 5/2/78	Rod similar to ML-2(1)	40 R/h contact 50 mR/h at 1 m	28/2/78
ML-6(2)	XE 074 866	MRS 5/2/78	Rod similar to ML-2(1)	25 R/h contact 100 mR/h at 1 m	13/2/78
ML-6(2)B	XE 074 866	Helicopter search 5/4/78	Second rod similar to ML-2(1)	25 R/h contact 100 mR/h at 1 m	5/4/78
ML-7(2)	XE 049 861	MRS 5/2/78	Rod similar to ML-2(1)	50 R/h contact 100 mR/h at 1 m	13/2/78
ML-8(2)	XE 090 881	MRS 5/2/78	Rod similar to ML-2(1)	100 R/h contact 150 mR/h at 1 m	13/2/78
ML-9(2)	XE 028 845	MRS 5/2/78	Rod similar to ML-2(1)	20 R/h contact 125 mR/h at 1 m	2/3/78
ML-10(2)	XE 251 946	MRS 7/2/78	Rod similar to ML-2(1)	15 R/h contact 50 mR/h at 1 m	3/3/78
ML-11(2)	XE 300 975	MRS 7/2/78	Rod similar to ML-2(1)	12 R/h contact 170 mR/h at 1 m	3/3/78
ML-11(2)B	XE 300 975	Helicopter search 5/4/78	Small flakes		6/4/78
ML-12(2)	XE 100 885	MRS 7/2/78	Rod similar to ML-2(1)	10 R/h contact 80 mR/h at 1 m	6/3/78
ML-12(2)B	XE 100 885	Helicopter search 5/4/78	Second rod similar to ML-2(1)	10 R/h contact 80 mR/h at 1 m	6/4/78
ML-13(2)	XE 125 879	MRS 8/2/78	Rod similar to ML-2(1)	6 R/h contact	3/3/78
ML-14(2)	XE 131 884	MRS 8/2/78	Rod similar to ML-2(1)	60 R/h contact 150 mR/h at 1 m	4/3/78
ML-15(2)	XE 159 903	MRS 7/2/78	Rod similar to ML-2(1)	33 R/h contact 100 mR/h at 1 m	26/2/78
ML-16(2)	XE 206 936	MRS 7/2/78	Rod similar to ML-2(1)	60 R/h contact 80 mR/h at 1 m	28/2/78
ML-17(2)	XE 228 932	MRS 8/2/78	Rod similar to ML-2(1)	12 R/h contact 60 mR/h at 1 m	3/3/78
ML-18(2)	XE 219 912	MRS 8/2/78	Rod similar to ML-2(1)	7 R/h contact 150 mR/h at 1 m	5/3/78
ML-19(2)	XE 230 913	MRS 8/2/78	Rod similar to ML-2(1)	10 R/h contact 150 mR/h at 1 m	5/3/78
ML-20(2)	XE 318 961	MRS 8/2/78	Rod similar to ML-2(1)	12 R/h contact 70 mR/h at 1 m	5/3/78
ML-21(2)	XE 325 968	MRS 8/2/78	Rod similar to ML-2(1)	15 R/h contact 80 mR/h at 1 m	5/3/78
ML-23(2)	XE 354 974	MRS 10/2/78	Rod similar to ML-2(1)	6 R/h contact 30 mR/h at 1 m	5/3/78
ML-25(2)	CA 537 066	MRS 10/2/78	Flaky slice of cinderlike material approx. 30mm long	8 R/h contact 30 mR/h at 1 m	6/3/78

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Summary of Fragments Recovered (cont'd)

Hit No. (Note 1)	Position (Note 2)	Date & Means of Discovery	Physical Description	Gamma Radiation Field* (Note 3)	Date of Recovery
ML-26(2)	XF 493 115	MRS 10/2/78	Metal Cylinder 250mm long x 100mm diam.	10 R/h contact 80 mR/h at 1 m	12/3/78
ML-27(2)	CA 839 185	MRS 10/2/78	Horseshoe shaped metal piece 100mm across, 50mm thick	6 R/h contact 300 mR/h at 30cm	5/3/78
ML-28(2)	CA 911 261	MRS 10/2/78	Cylinder similar to ML-26(2)	15 R/h contact	17/3/78
ML-29(2)	CA 919 256	MRS 10/2/78	Cylinder similar to ML-26(2)	10 R/h contact 600 mR/h at 30cm	2/3/78
ML-30(2)	XE 333 960	Helicopter search 26/2/78	Particle	150 mR/h near contact	12/3/78
ML-32(2)	XE 335 965	MRS 6/3/78	Sliver about 10mm by 100mm	30 mR/h at 1 m	6/3/78
ML-33(2)	CA 854 238	Helicopter search 20/3/78	Cylinder similar to ML-26(2)		23/3/78
ML-34(2)	CA 865 245	Helicopter search 22/3/78	Cylinder similar to ML-26(2)		23/3/78
ML-35(2)	XE 128 874	Air search August 1978	Rod similar to ML-2(1)	8 R/h (and 15 rad/h) near contact; 100 mR/h (and 200 mrad/h) at 30 cm	August 1978
ML-1(3)	DA 054 304	MRS 10/2/78	Cylinder similar to ML-26(2)	10 R/h contact 400 mR/h on one end at 30 cm 800 mR/h on opposite end at 30 cm	5/3/78
ML-2(4)	EA 390 744	Visual from ground 28/1/78	Complex shaped object; concave thin plate or cracked cylinder end with tubular (double) braces and related parts	15 R/h contact	19/2/78
ML-1(9)	WE 030 110 Murky Lake area	Helicopter and ground search 22/2/78	6 particles	100–2000 mR/h contact	22/2/78
	WE 123 193 Snowdrift area	Helicopter and ground search 10/2/78	97 particles	5–1000 mR/h contact	14/2/78 to 21/2/78
ML-2(9)	WE 205 220	Helicopter search 12/2/78	Flake	40 mR/h contact	Not recovered (Note 5)
ML-3(10)	VE 675 155	MRS 20/2/78	Chunk of slag about 25mm x 15mm x 10mm	500 R/h contact	23/2/78
ML-5(10)	VE 762 261	MRS 1/3/78	Rod similar to ML-2(1)	10 R/h contact 200 mR/h at 1 m	5/3/78
ML-5(10)B	VE 762 265	MRS 1/3/78	Second rod similar to ML-2(1) & sliver of material		5/3/78
ML-6(10)	VE 716 218	MRS 2/3/78	End of rod approx. 20mm long	5 R/h contact 40 mR/h at 1 m	9/3/78
ML-7(10)	VE 845 225	MRS 2/3/78	Black chunk of material 25mm dia.	20 R/h contact 90 mR/h at 1 m	9/3/78
ML-8(10)	VE 937 249	MRS 2/3/78	Sliver about 80mm long x 3mm wide + small particle 3mm in diameter	25 R/h contact 110 mR/h at 1 m	9/3/78
ML-10(10)	VE 735 140	MRS 10/3/78	Irregular flake approx. 20mm x 15mm, + 6 particles	100 mR/h at 1 m	11/3/78
ML-11(10)	VE 650 137	MRS 10/3/78	Particles	10 mR/h at 1 m	11/3/78
ML-14(10)	VD 505 970	MRS 11/3/78	Small particle	10 mR/h at 1 m	19/3/78
ML-15(10)	VD 532 983	MRS 11/3/78	Small flake approx. 7mm long	20 mR/h at 1 m	19/3/78

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Summary of Fragments Recovered (cont'd)

Hit No. (Note 1)	Position (Note 2)	Date & Means of Discovery	Physical Description	Gamma Radiation Field* (Note 3)	Date of Recovery
ML-17(10)	VE 725 132	MRS 11/3/78	Small fragment approx. 10mm x 10mm x 5mm	40 mR/h at 1 m	21/3/78
ML-18(10)	VE 643 130	Helicopter 11/3/78	Specks in snow	40 mR/h at 1 m	11/3/78
ML-19(10)	VE 651 121	Helicopter 11/3/78	Specks in snow	40 mR/h at 1 m	11/3/78
ML-20(10)	VE 665 103	MRS 11/3/78	Sliver	40 mR/h at 1 m	19/3/78
ML-21(10)	VD 524 943	MRS 12/3/78	Long sliver	10 R/h at 50mm 105 mR/h at 1 m	16/3/78
ML-22(10)	VE 700 090	MRS 12/3/78	Particle Particle	8 mR/h at 1 m 4 mR/h at 1 m	19/3/78 24/3/78
ML-24(10)	VE 836 103	MRS 12/3/78	Flake approx. 15mm square	100 mR/h at 1 m	27/3/78
ML-25(10)	VE 657 105	Helicopter 14/3/78	Small triangular shaped flake	10 mR/h at 1 m	19/3/78
ML-27(10)	VE 685 110	Helicopter 17/3/78	Particle	8 mR/h at 1 m	24/3/78
ML-28(10)	VD 555 990	Helicopter 17/3/78	Small Flake	80 mR/h at 1 m	21/3/78
ML-32(10)	VE 905 256	Air search August 1978	Small metallic flake 20 mm x 5 mm	3 R/h near contact 20 mR/h at 1 m	August 1978
ML-1(11)	VD 270 997	MRS 7/3/78	50mm dia. x 3mm thick, black plate, not flaky	40 R/h contact 200 mR/h at 1 m	8/3/78
ML-3(11)	VD 396 953	MRS 12/3/78	Very small specks in snow	300 mR/h contact 2 mR/h at 1 m	16/3/78
ML-4(11)	UD 460 630	Helicopter 12/3/78	Flat oval plate 140mm x 90mm x 35mm	40 R/h contact 900 mR/h at 1 m	16/3/78
ML-5P(11)	UD 610 590	Ground search 14/3/78	19 particles		21/3/78
ML-6(11)	VD 349 827	MRS 14/3/78	Chip approx. 3mm square	10 R/h contact, 10 mR/h at 1 m	16/3/78
ML-6(11)B	VD 349 827	Helicopter 8/4/78	Specks in snow		8/4/78
ML-7(11)	VD 411 805	MRS 14/3/78	Chip approx. 10mm long	4 R/h near contact, 40 mR/h at 1 m	16/3/78
ML-7(11)B	VD 411 805	Helicopter 8/4/78	Speck in snow		8/4/78
ML-8(11)	UD 637 531	MRS 26/3/78	1 Particle	1 mR/h at 1 m	29/3/78
ML-8(11)B	UD 637 531	Helicopter 8/4/78	Speck in snow		8/4/78
ML-9(11)	UD 505 539	MRS 26/3/78	2 Particles	1 mR/h at 1 m	29/3/78
ML-10P(11)	VD 280 670 area Simpson Islands	Ground search 30/3/78	8 Particles		30/3/78
ML-1(12)	PU 125 170	MRS 31/3/78	Sheet metal approx. 220mm x 80mm x 3mm + 1 small particle		5/4/78
ML-1P(13)	NT 760 435	Ground search 27/2/78	2 particles	1 mR/h at 1 m	27/2/78
ML-2P(13)	UD 670 165 area Great Slave Lake	Ground search 13/3/78	19 particles		13/3/78
ML-3P(13)	NS 950 815 area Buffalo Lake	Ground search 19/3/78 and 22/3/78	19 particles	1-18 mR/h at 1 m	19/3/78 and 22/3/78
ML-4P(13)	NT 685 370 Hay River area	Ground search Feb.-Mar. 78	48 particles		Completed 9/3/78

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Summary of Fragments Recovered (cont'd)

Hit No. (Note 1)	Position (Note 2)	Date & Means of Discovery	Physical Description	Gamma Radiation Field* (Note 3)	Date of Recovery
ML-5P(13)	PT 380 465 Pine Point area	Ground search Feb.-Mar. 78	176 particles		Completed 5/3/78
ML-6P(13)	UC 565 857 area Fort Resolution	Ground search Feb. - Mar. 78	110 particles		Completed 1/3/78
ML-7P(13)	NS 715 330	Ground search 6/4/78	Speck in snow		6/4/78
ML-8P(13)	PU 100 000 area Great Slave Lake	Ground search 7/4/78	6 particles		7/4/78
ML-1P(14)	VC 540 250 area Tsu Lake	Ground search 23/3/78	Contaminated snow No particles found		
ML-2P(14)	WB 000 830 area Pilot Lake	Ground search 2/4/78	36 small particles		2/4/78
ML-3P(14)	WD 110 335 area Rutledge Lake	Ground search 5/4/78	7 small particles		5/4/78
ML-4P(14)	VD 070 070 Rocher River	Ground search 2/4/78	2 small particles		2/4/78

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Radioactive Particles Recovered During Summer 1978 (Note 6)

(with some examples of radioactivity level)

Position		Particles Recovered
HAY RIVER, NWT	— Community (average 19 μR/h at 1 meter, 80 mrad/h near contact)	119
	Adjacent highways	7
PINE POINT, NWT	— Community (average 24 μR/h at 1 meter, 90 mrad/h near contact)	422
	Adjacent highways	112
FORT RESOLUTION, NWT	— Community (average 22 μR/h at 1 meter, 140 mrad/h near contact)	494
	Adjacent highways	414
SNOWDRIFT, NWT	— Community (average 30 μR/h at 1 meter, 9 mrad/h near contact)	9
	Frontier Lodge	1
FORT SMITH, NWT	— Community (average 10 μR/h at 1 meter, 28 mrad/h near contact)	1,110
	Adjacent highways	230
SALT RIVER, NWT	— Community	11
BELL ROCK, NWT	— Community	65
CARLSON LANDING, ALTA	— Community	2
FORT FITZGERALD, ALTA	— Community	1
HAY CAMP, ALTA	— Community	2
PEACE POINT, ALTA	— Community	20
FORT CHIPEWYAN, ALTA	— Community (average < bkgd at 1 meter, 11 mrad/h near contact)	14
MACDONALD LAKE, NWT	— Camp sites (East end)	11
BUFFALO LAKE, NWT	— Camp sites	3
TALSTON RIVER, NWT	— Power dam site	6
TSU LAKE, NWT	— Camp sites	2
NAUTAWA LAKE, NWT	— Camp sites	2
PILOT LAKE, NWT	— Fishing lodges	10
CHAMPAGNE LAKE, NWT	— Camp sites	2
HOOK LAKE, NWT	— Camp sites	2
THUBUN LAKE, NWT	— Fishing lodge	1
JACKFISH LAKE, NWT	— Camp site	1
SCHAEFER LAKES, NWT	— Camp site	1
OULTON LAKE, NWT	— Camp site	1
Unnamed lakes and along rivers	— Camp sites	8
Railway Line — HAY RIVER to PINE POINT		51
	Total recovered during summer	3,134

Notes:

1. Sequential hit numbers missing from summary identified suspected hits which were later deleted for the following reasons:

a) Confirmed or probable natural radiation source	—	48
b) Confusion in location, or MRS error	—	11
c) Unable to confirm by later search	—	25
d) Review of spectrum indicated false hit	—	23
e) Search found natural, non-radioactive feature	—	3
		110

2. Position locations are from Ten Thousand Meter Universal Transverse Mercator Grid, Zones 75 and 85, Canadian Topographical Map Series 1:250,000.

3. Gamma Radiation Fields were measured in the field at the time the fragment was first located and identified by a ground search party. The "contact" measurements in many cases were made in contact with the covering snow which may have been several centimeters thick.

   Whenever the Gamma Radiation Field is left blank, it means that the information is not readily available; however, all of the fragments and particles recovered were radioactive with the single exception of Hit Number ML-10(1).

4. Hit Numbers ML-35(1) to ML-41(1), ML-35(2) and ML-32(10) were located and recovered by contract during the Phase II Program.

5. ML-2(9) was confirmed as a flake of material by ground observation, but was blown away by downwash from a helicopter and could not be re-located.

6. A total of 3,134 small radioactive particles were located and recovered by ground search parties employed by the Phase II contractor in checking communities, connecting roads and railways, commercial fishing lodges, trapping and fishing camp sites and other inhabited or travelled areas.

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Appendix E

Pick-up and Transportation of Recovered Material

For the safe conventional transportation of radioactive material great effort has been put into the development of suitable containers. A number of container models have been produced by Atomic Energy of Canada Radiochemical Company, and approved for use by AECB after testing to meet stringent conditions.

The provision of containers to meet the sudden needs of the Cosmos 954 clean-up operations rapidly depleted the stock on hand, forcing the manufacture of additional stock and the use of other containers under strict control. Containers used are listed in Table 18.

Lead-shielded containers permit safe storage and shipment of radioisotopes and other radioactive materials. When debris began to be recovered, there developed an immediate shortage of conventional containers, and a number of special safe substitutes were urgently constructed. The F112 and F113 models were excellent for field use, except for the small capacity of the lead insert.

A 9000-lb container (F233) was kept on hand in case a large piece of reactor core was discovered, but was not required.

Standard drums, pails and cans, often with garbage bag liners, were used for low activity material. These containers overcame the objection to some of the shielded containers — the small cavity — but introduced a hazard in contamination because of difficulties in closing gaskets in the field under winter conditions. Since recovered material almost invariably included snow or ice (in Phase I), thawing of this raised the possibility of leakage of contaminated water. If material could not be kept frozen in transport, the trick of placing the container in a larger one was often employed, and contamination of aircraft and other transport was successfully avoided.

Ingoing and outgoing shipments of containers were under continuous examination by health physics staff, verifying that no contamination existed.

Field and Shipping Operations

The procedure for recovery of debris, handling and shipment to Pinawa included several steps:

1. Following location of radioactive material in the field, the pick-up team was sent to the spot (by helicopter or other means) and proceeded to recover the material. This might require use of long-handled tongs and lead-lined containers in the snow. Health physics capability was always part of the pick-up team in order to monitor exposure and to prevent contamination.

TABLE 18

Types of Containers*

Type	Number Available	Cavity dia. & ht. (inches)	Amount of Shielding (inches of lead)	Wt. (lb.)	Comments
F233	1	13 x 20	7	9000	standby
F112	7	3 x 4	1	135	18"x20" drum
F113	12	3 x 4	2	210	18"x20" drum
F239	18	very small	1	45	5 gal. pail
FC1**	1	2 x 4 x 11 rect.	2+	500	For ML-1(1)
FC2**	1	22 dia. x 60 high	0-1	500	partial shielding
FC3***	1	6 x 12	1-2	450	
FC4***	1	6 x 12	1-2	450	18"x20" drum
FC6***	14	4 x 6	1 3/4	275	18"x20" drum
FC7***	6	5 x 11	1 1/4	275	18"x20" drum
46 gallon	200+	22 x 36	—	—	
25 gallon	200+	18 x 29	—	—	
18 gallon	—	—	—	—	garbage pail
5 gallon	30	10 x 15	—	—	
1 gallon	100+	6 x 8	—	—	not used as outers

* Dimensions in inches for consistency with suppliers' standards
** Made in Alberta to meet needs of the program
***Made in Ottawa to meet needs of the program

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2. Material was brought first to Yellowknife, then sent to Canadian Forces Base (CFB) at Namao. Here space was made available by DND for samples to be held, repacked if necessary, given preliminary examination, and then shipped under escort to CFB: Winnipeg.
3. At CFB: Winnipeg a representative of WNRE at Pinawa met the plane with a truck and material was transported to Pinawa.

A travelling form accompanied each sample throughout its journey, and at each point of arrest or transshipment it was signed by the receiving person. For legal purposes, since each sample was considered a piece of evidence for anticipated dealings with the USSR, this procedure was followed consistently (Figure 31).

All but one shipment to Winnipeg were made in CF aircraft. The first shipment of debris went by common carrier, with all requirements of safety being met and with no risk to passengers, as a matter of expediency.

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.TOMIC ENERGY CONTROL BOARD

OPERATION MORNING LIGHT

SAMPLE TRANSMITTAL SHEET.

TO BE FILLED IN BY ORIGINATOR

Container Tag No. X0141 Date 19 Mar 78

UTM Grid Co-ordinates ML 14(10) VD 505-970

Sample: Field Identification ______ (use reverse side if necessary)

Originated by ______ Location ______

TO BE FILLED IN EACH TIME POSSESSION IS TRANSFERRED

(1) This sheet is to accompany sample at all times.
(2) All transfers are to be recorded and singed by individuals concerned.
(3) Any change to the sample should be noted and accounted for.
(4) All information derived for each sample should accompany this sheet.
(5) Sample should be stored only in secure (locked) place.

Date	Transferred From	Transferred to	Purpose, Actions Performed & Notes
19 Mar 78	1 sample	800 mR/hr @	2" } for the above
		15 mR/hr @	1 meter
	Note. Bl Plastic bag		not marked with
	small pcs. of F.P.		
[illegible]	[illegible]		
21 mar 78	[illegible]	W R Taylor	Storage at Ed
22 mar 78	W R Taylor	Michael [illegible]	Storage at Ed
30 MAR 78	Michael [illegible]	[illegible]	Escort to Winnipeg
30 MAR 78	[illegible]	V B [illegible]	[illegible] CFB Wpg
MAR 31 1978	[illegible]	[illegible]	to [illegible]
Mar 31/78	[illegible]	R W Pollock	Send to WMA Bunker.

FIGURE 31 Example of "sample transmittal sheet" that accompanied all recovered debris from first recovery to final storage at WNRE.

FOR USE BY OPERATION HQ CFB NAMAO ONLY:

Packaging ID F-239-7

HIT NUMBER ML 14(10)

Dose Rate (Packaged) mR/hr Date: 22.3.78

	Contact	1 meter
SIDE	2	0.004
TOP	0.15	0.006

R-1 Mar.2, 1978.

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Appendix F

Records of Exposure to Radiation of Search and Other Personnel

Records were kept for all personnel in any position to be exposed to radiation. Personal dosimeters were issued to those directly involved in search and recovery operations, and to all those handling or examining debris under laboratory conditions. Also, a limited number of warning dosimeters were made available to members of the public, particularly local inhabitants, who needed to enter areas where they might encounter radioactive material from the satellite. The dosimeters employed were of three sorts:

a) *Film dosimeters.* The Canadian search personnel wore film dosimeters supplied by the Radiation Protection Bureau of Nation Health and Welfare (RPB), which processed the films after each wearing period and issued dose reports. The US staff used their own regular dosimeters.

b) *Direct reading dosimeters.* Search teams and those involved in shipping the recovered items also wore a direct reading dosimeter (DRD), usually a quartz fibre electroscope, which permitted them to keep track of day-to-day exposures and also provided a backup for the film dosimeter.

c) *Warning dosimeters.* Warning dosimeters give a digital display of the accumulated exposure in milliroentgens and also produce an audible signal or "beep" at a rate depending upon the radiation intensity. A sharp increase in the beep rate gives warning of a radioactive fragment in the vicinity. These dosimeters were made available to members of the public, through the co-operation of the local RCMP detachments, along with simple instructions on how to use them and the action to take if the beep rate increased significantly.

Whole Body Dose Records

A summary of the whole body dose data for the operations is given in Table 19. Generally, the doses are based on film dosimeter measurements, but in the case of U.S. staff (which are included) the doses are based on DRD measurements.

The 302 people who wore dosimeters during Phase I field search were personnel from the Atomic Energy Control Board, Atomic Energy of Canada Limited, the Department of Energy, Mines and Resources, the Department of National Defence, Environment Canada, and the US Nuclear Emergency Search Team (NEST). The 21 who wore dosimeters during Phase II field search were mostly staff of the Canadian consultant who performed this work under contract to the Federal Government, together with a few members of the AECB staff.

TABLE 19

Whole Body Dose Summary

Type of Work	No. of people issued with dosimeters	No. of people who received a dose	Collective whole body, dose, man-rem.
Field search — Phase I	302	106	6.30
Field search — Phase II	21	6	0.31
Laboratory Analysis	35	35	2.00
Overall programme	353	145	8.61

* Note that while the collective whole body dose is additive in this table, the numbers of people involved are not; this is because a few people were involved in both phases of the field search.

The doses received while performing the laboratory analyses represent exposure at the Whiteshell Nuclear Research Establishment of AECL.

The distribution of doses received during Phases I and II field search is given in Figure 32; only those who received a measurable dose, i.e. 110 people, are included in this distribution. Of these, two received a measurable dose in both phases.

Other Dosimetry

In addition to measurement of the whole body dose, usually due to external gamma radiation, film dosimeters are capable of measuring the skin dose resulting from low penetration radiation. During Phase I, all field staff wore heavy arctic clothing which provided good protection for the skin against low penetration radiation, so that skin doses during this phase have been taken to be numerically equal to the whole body dose for each individual. Lighter clothing was worn during Phase II and skin dose as measured by film dosimeters was recorded for this period; of the 6 people who received a measurable dose during Phase II, only 3 received skin doses that exceeded the whole body dose. The highest recorded skin dose was 400 mrem during Phase II and 470 mrem during Phase I.

Urine samples were submitted by the field search teams for analysis of tritium and mixed fission products by RPB; no evidence was found of internal contamination.

Comments

A total of 353 people wore personal dosimeters at one time or another during the operations (see Table 19). Of

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these, 145 received a measurable dose (⩾10 mrem) to the whole body. The collective whole body dose for the whole operation was 8.61 man-rem. The highest individual accumulated whole body dose was 470 mrem which is also the highest recorded individual skin dose; both of these doses are well below the maximum permissible doses for atomic radiation workers, i.e. 5,000 mrem per year for whole body exposures and 30,000 mrem per year for skin exposures.

The highest individual dose as well as the highest collective dose occurred during Phase I which corresponds to the period when most radioactive fragments were being recovered and the largest number of people were employed.

There was no evidence of internal contamination during the whole period.

Members of the public who used warning dosimeters did not receive any dose above natural background.

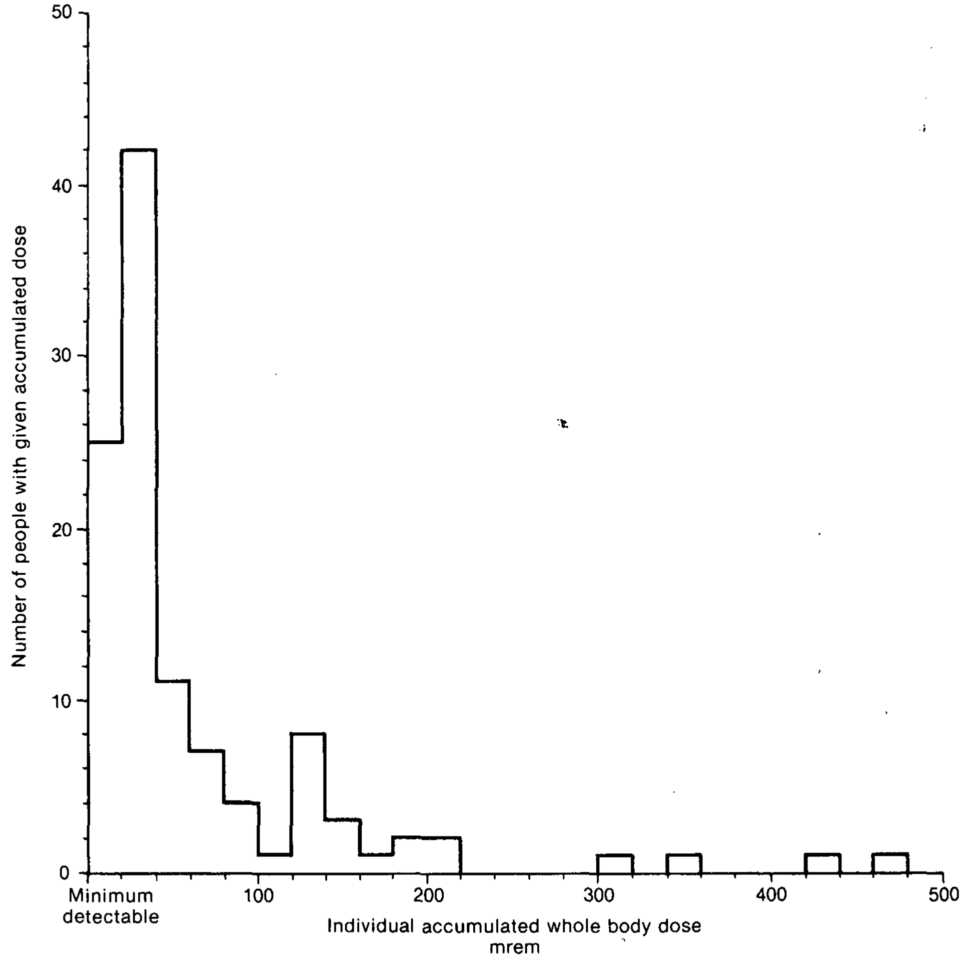

FIGURE 32 Distribution of individual doses received during Phases I and II of the field search and recovery operations.

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Appendix G

International Aspects

The Cosmos 954 episode was Canadian in the sense that it fell within Canadian borders, but a number of international aspects immediately became apparent.

1. The first one is obviously that the US had advance knowledge of the coming re-entry and, when this occurred, was best able to calculate the landing trajectory. In the circumstances, Canada was dependent upon this ability. Furthermore, the US possessed a forewarned Task Force with experience in location and clean-up of nuclear material. Thus, most operations in Phase I were joint in the sense that Canadian and US forces were both involved, the US team officially assisting the Canadians.
2. From the start, it was recognized that technical data arising from study and analysis of recovered debris might be of interest to other nations, but it was also clearly stated that these data would be the property of Canada. This was because in any eventual claim against the USSR, Canada would be the claimant. Data were made available to the US team in order to assist in refining ballistic studies that were concerned with the zone of fall of fragments of the satellite, but the interpretation of data from the health and safety viewpoints was a Canadian responsibility.
3. Finally, there was naturally much sudden interest on the part of other countries in the techniques employed in the Phase I and II operations for location and removal of debris. Cosmos 954 introduced to the world the spectre of unplanned re-entry of nuclear material, and others wish to profit by the experience gained in this event. Thus there have been several contacts with other governments, both directly by the AECB and through the Department of External Affairs. The publication by the Geological Survey of Canada of several papers on air-borne search techniques has provided answers to the most obvious questions raised by others. The following APPENDIX (H) summarizes the obvious lessons learned from this event.

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Appendix H

Lessons Learned from COSMOS 954 Re-entry

The re-entry of Cosmos 954 over the Northwest Territories of Canada on 24 January, 1978 offers an example of the problems presented to a country by such an event.

Earth-orbiting satellites will always re-enter at a low angle, and if burn-up is incomplete debris may be scattered over a distance of several hundred kilometres. If finely divided material is produced, it will be affected by the weather conditions existing at the time, chiefly by wind which may distribute such material over very large areas.

The major requirements posed by the event were:

1) Knowledge of the trajectory of the satellite on and following re-entry;
2) the capability of moving men and material across areas of the northern terrain under mid-winter conditions, and of setting up base camps for remote operations;
3) a means of surveying a vast and rather ill-defined area using air-borne radiation detection equipment, flying at controlled speeds and elevations, precisely locating detected items for subsequent recovery, and landing at will for material identification and recovery;
4) a means of safely recovering fragments and transporting them to a central handling and storage facility, preventing the exposure of search personnel, carriers, representatives of the press, and general public.

To meet these requirements required assistance from NORAD and U.S. expertise for the trajectory, and involved coordinated efforts from three main agencies, one responsible for operations and logistics, one with airborne detection experience, and one responsible for health and safety aspects of radioactive contamination.

With respect to what countries can do to prepare for such an eventuality, it is not likely that many will be able to afford to maintain on stand-by basis the full complement of personnel, equipment and instruments necessary to carry out a search and recovery operation of this sort. A few countries, notably USA and probably USSR, UK and France, do maintain resources for response to nuclear accidents. Certainly no single Canadian agency had available "on the shelf" the instrumentation needed, nor the complement of trained personnel to use it. As a result of this experience, however, the Canadian capability has now been greatly improved. To obtain the personnel needed meant the disruption of regular work programs, and although all agencies responded readily, the cost of this interference is a feature that should be recognized.

The Cosmos 954 episode now offers some experience but of course it is not all applicable elsewhere. It relates to subarctic winter conditions, it relates to a sparsely populated area, it relates to a particular type of terrain, and so on. The obvious aspects are the following:

1) Countries lying beneath the orbit of a failing satellite should be advised of estimated re-entry as far in advance as possible.
2) Without information on the major parameters of a nuclear-powered satellite's source — size, power, fuel type, degree and type of protection, etc. — a search will be hampered by uncertainty.
3) Policy on release of information should be clarified and explained publicly at the start of operations. It would be desirable for contiguous countries to seek a common position on public release of information.
4) A single coordinator for overall operations is essential.
5) Central control of communications for both search and recovery operations, and for public relations is necessary. Support capability should include printing, photography, telex, recording, radio and telephone.
6) Access to appropriate radiation detection equipment, or knowledge of a source of supply, is important.
7) Under the northern winter conditions that existed during Phase I of the Cosmos 954 operations, precise location of debris based on airborne survey requires a system of ground-positioned navigation beacons.
8) Containers suitable for transport, and a safe location for storage (interim or long term) of recovered material, are necessary.
9) It is essential to ensure means for quick analysis of debris, particularly with respect to the solubility of fragments small enough to be ingested or inhaled, and to identify the soluble components and their potential hazards to health. Determination of shape and mass parameters (as well as meteorological conditions at the time) will also be important in developing knowledge of airborne distribution of tiny particles. Analysis of drinking water supplies that may be contaminated by soluble debris should be begun without delay.
10) If there is any likelihood of legal follow-up or international litigation, a system for documentation and maintaining full records of debris recovery, at "rules of evidence" level, may be necessary. Costs of the operation must also be

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accounted in a standardized fashion by all participating agencies, in order to permit prompt preparation of eventual financial claims.

It might be suggested that the UN Committee on Peaceful Uses of Outer Space (UNCOPUOS) could refer the problem of search, recovery and clean-up to an appropriate health group such as WHO since the problem is essentially one of health physics as opposed to science and technology. The U.N. Disaster Organization is another possibility. Such an organization could explore the feasibility and desirability of collecting together a central pool of equipment as a long term project. In the short term, the group could document resources already existing in certain countries willing to make those resources available. A mechanism for requesting and organizing the use of such resources would also be required. At time of writing, there is an ongoing activity in UNCOPUOS, Canada participating, to investigate such possible actions.

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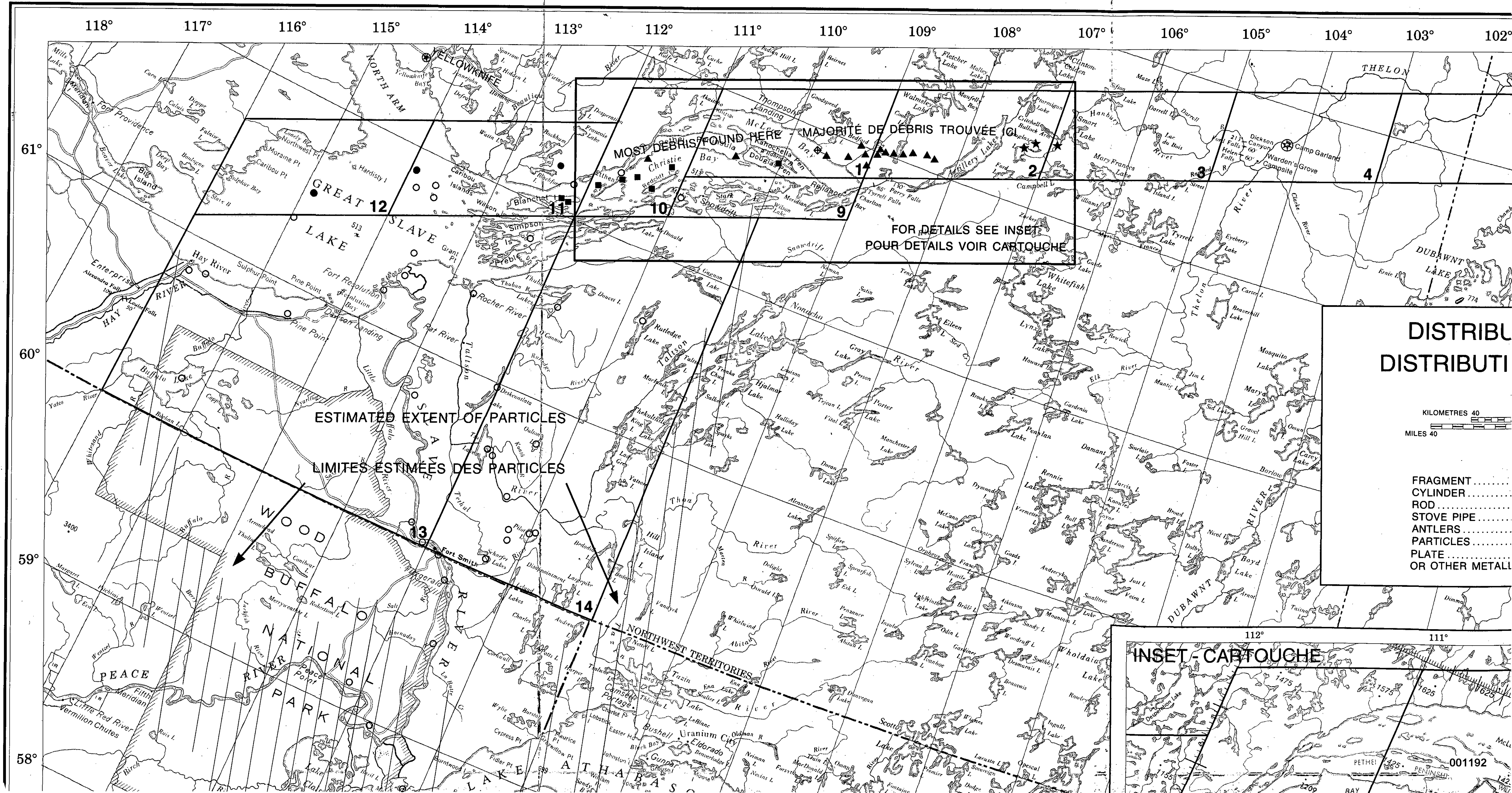

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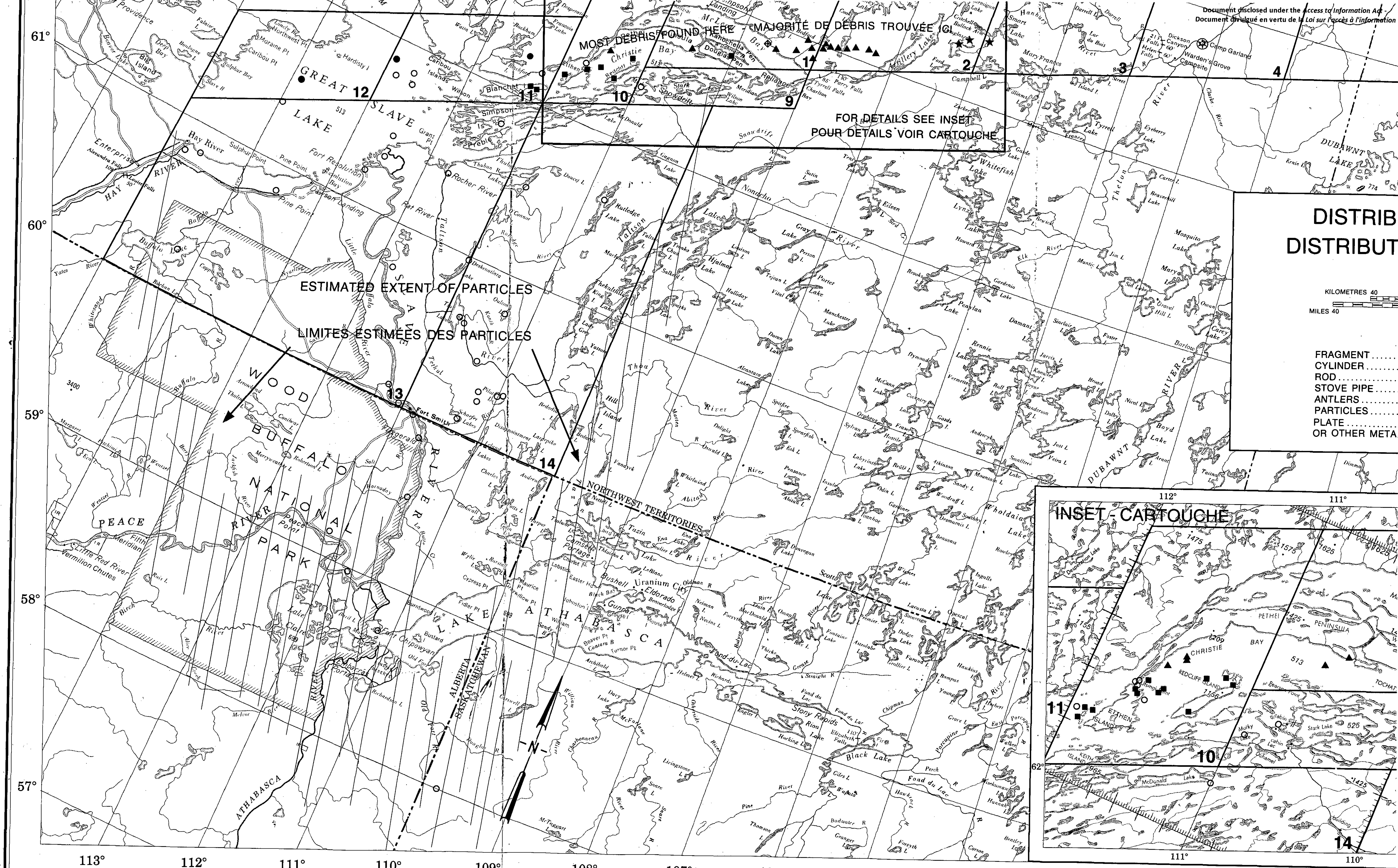

PRODUCED FOR THE ATOMIC ENERGY CONTROL BOARD BY THE SURVEYS AND MAPPING BRANCH,
DEPARTMENT OF ENERGY, MINES AND RESOURCES, OTTAWA, CANADA.

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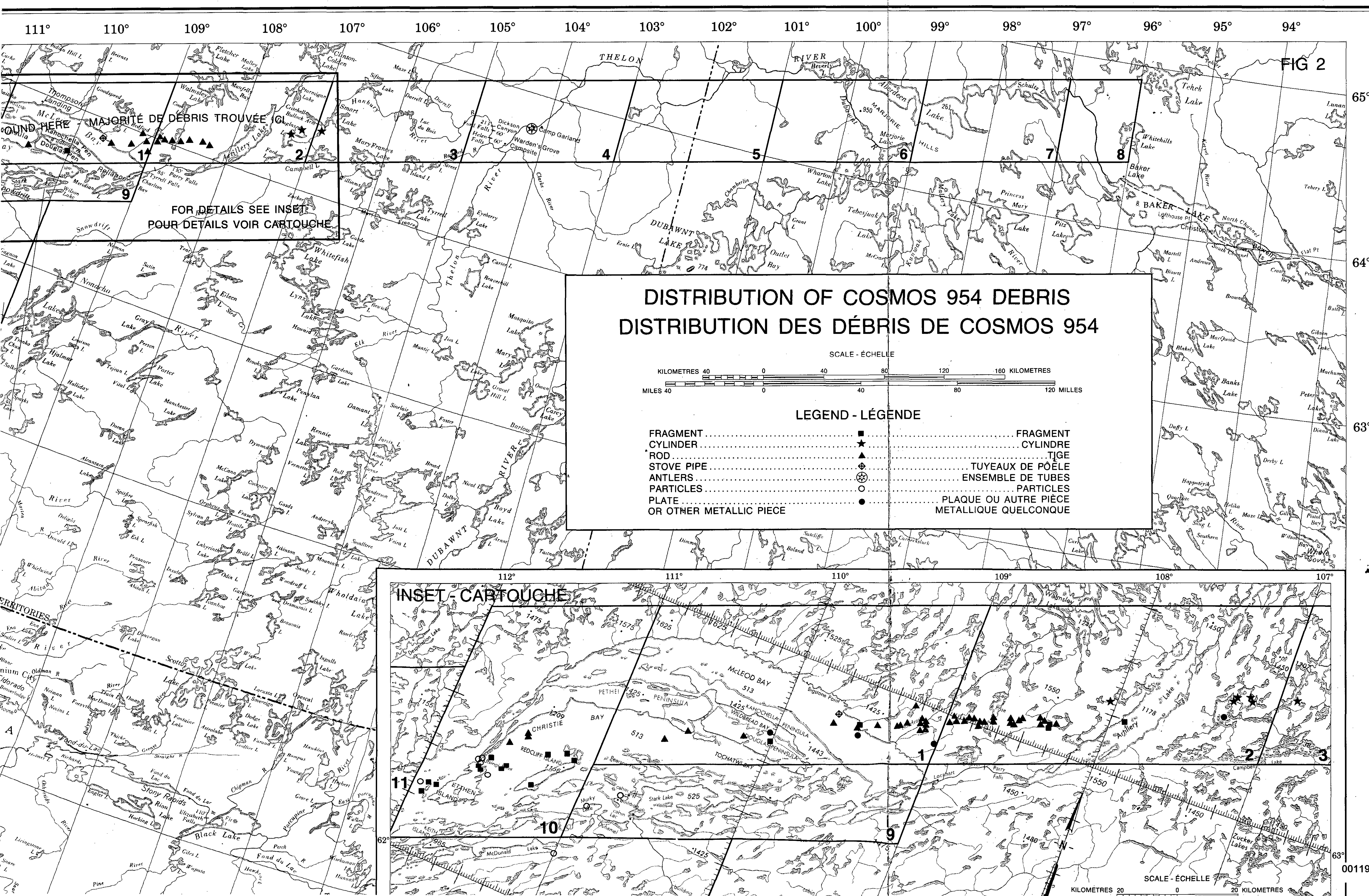

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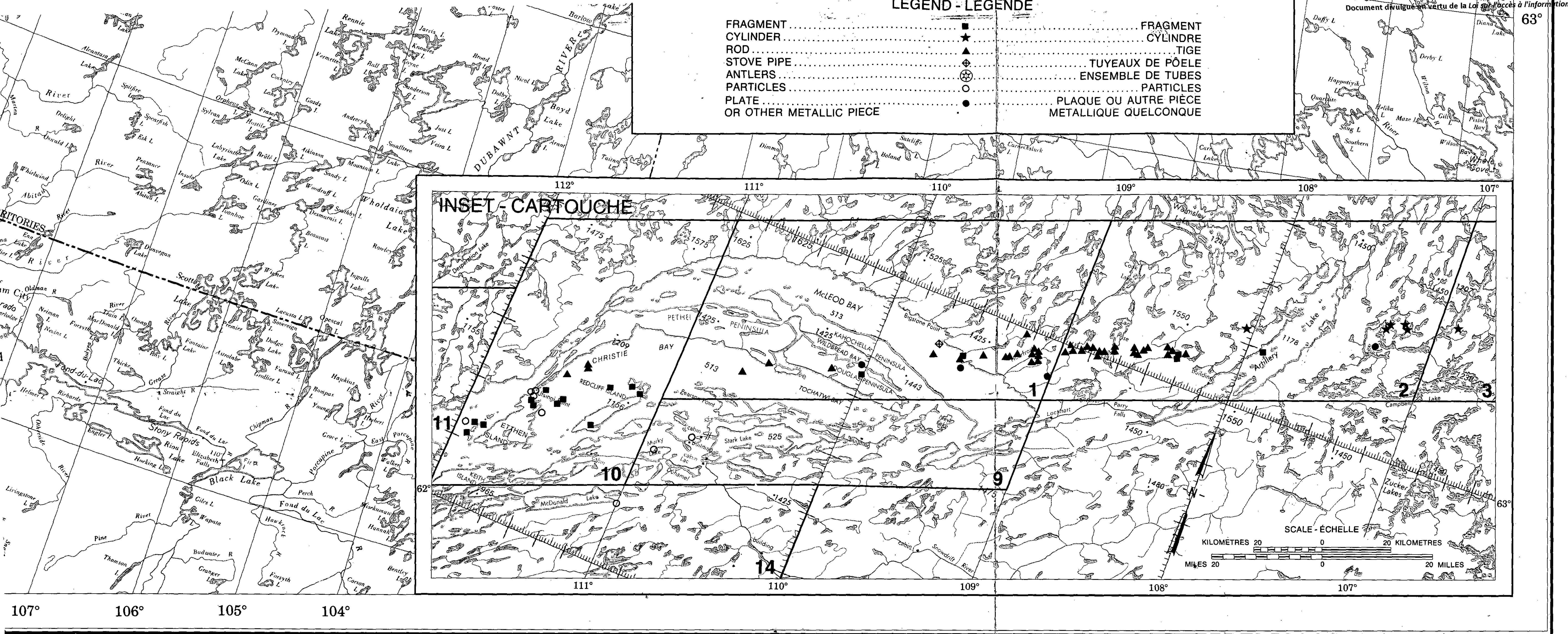

ÉTABLIE POUR LA COMMISSION DE CONTRÔLE DE L'ÉNERGIE ATOMIQUE PAR LA DIRECTION DES LEVÉS ET DE LA CARTOGRAPHIE, MINISTÈRE DE L'ÉNERGIE, DES MINES ET DES RESSOURCES, OTTAWA, CANADA.

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ANNEX B

TEXTS OF DIPLOMATIC COMMUNICATIONS BETWEEN THE DEPARTMENT OF EXTERNAL AFFAIRS AND THE EMBASSY OF THE UNION OF SOVIET SOCIALIST REPUBLICS

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LIST OF DIPLOMATIC COMMUNICATIONS

Department of External Affairs Note No. FLO-0359 to the Embassy of the Union of Soviet Socialist Republics, Ottawa, February 8, 1978.

Department of External Affairs Aide-Mémoire to the Embassy of the Union of Soviet Socialist Republics, Ottawa, February 8, 1978.

Embassy of the Union of Soviet Socialist Republics Note No. 18 to the Department of External Affairs, Ottawa, February 20, 1978.

Department of External Affairs Note No. FLO-0497 to the Embassy of the Union of Soviet Socialist Republics, Ottawa, February 28, 1978.

Department of External Affairs Note No. FLO-0532 to the Embassy of the Union of Soviet Socialist Republics, Ottawa, March 3, 1978.

Embassy of the Union of Soviet Socialist Republics Note No. 27 to the Department of External Affairs, Ottawa, March 21, 1978.

Department of External Affairs Note No. FLO-0840 to the Embassy of the Union of Soviet Socialist Republics, Ottawa, April 13, 1978.

Embassy of the Union of Soviet Socialist Republics Note No. 37 to the Department of External Affairs, Ottawa, May 31, 1978.

Department of External Affairs Note No. FLO-2884 to the Embassy of the Union of Soviet Socialist Republics, Ottawa, December 18, 1978.

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Department of External Affairs Ministère des Affaires extérieures

Canada

The Department of External Affairs presents its compliments to the Embassy of the Union of Soviet Socialist Republics and has the honour to refer to the 1968 Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space.

In accordance with Article 5, paragraph 1 of that Agreement, to which both Canada and the USSR are parties, the Government of Canada hereby wishes to notify the Government of the Union of Soviet Socialist Republics that component parts of a space object have been discovered on Canadian territory. These are believed to be component parts of the USSR Satellite Cosmos 954 which re-entered the earth's atmosphere in Canada on January 24, 1978. Some of these component parts were found to be radioactive. In light of the risk of hazards to persons and property in Canada, the Canadian authorities have carried out a comprehensive air and ground search for these parts and the search for additional parts is continuing. To date, the parts, as described in the attached annex, have been located in areas of Canada's Northwest Territories and are being removed to a safe location as local conditions permit. The

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Canadian authorities have taken every feasible precaution to limit to the greatest extent possible any harmful effects of these component parts on persons or property.

The Canadian Government reserves all its rights in international law on the matter of liability and compensation in relation to this incident. The Canadian Government will be raising this matter separately with the Government of the USSR in due course.

In accordance with Article 5(1) of the 1968 Agreement, Canada is also notifying the Secretary-General of the United Nations.

The Department of External Affairs avails itself of this opportunity to renew to the Embassy of the Union of Soviet Socialist Republics the assurances of its highest consideration.

O T T A W A, February 8, 1978

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Annex to Note to the Union of Soviet Socialist Republics, February ..

1. Search Area One: at the eastern end of Great Slave Lake, near Fort Reliance, N.W.T.

   Part no. 1:

   Description: metal piece, 23cm x 9 cm x 1.3cm, charred, emitting man-made radiation indicated by fission product spectrum.
   Location: 62° 50.5'N; 109° 29.5'W

   Part no. 2:

   Description: grey metal, 2cm x 2cm x 8cm, crushed ring, black liner, emitting man-made radiation indicated by fission product spectrum.
   Location: 62° 52.1'N; 109° 32'W

   Part no. 3:

   Description: metal pipe, 25cm in diameter, 30cm long; lightweight, containing Mn, Mg, Pb, Fe, Cu; associated fibre and metal parts.
   Location: 62° 52'N; 109° 40'W

   Part no. 4:

   Description: semi-circular metal plate, grey-black, 2cm x 2cm x 8cm, emitting man-made radiation.
   Location: 62° 57.3'N; 109° 08.5'W

   Part no. 5:

   Description: thin metal, leaf-ribbed, lightweight, 7cm in diameter, emitting man-made radiation.
   Location: 62° 54.3'N; 109° 01'W

2. Search Area Four: near Warden's Grove, on the Thelon River, N.W.T.

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Part no. 1

Description: metal struts, approximately 3cm long, attached to soft metal plate, emitting man-made radiation with technical characteristics indicating no fission products; activation products only.
Location: 63° 47.8'N; 104° 13.5'W.

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Department of External Affairs — Ministère des Affaires extérieures

Canada

A I D E - M E M O I R E

Answers to the following questions, which were originally asked on January 24 and reiterated on January 27, remain of interest to the Canadian authorities concerned with the search for and recovery of debris believed to be part of the Soviet satellite COSMOS 954:

1. <u>What is the nature and amount of fuel?</u>

   The power output, operating history, type of reactor (thermal or fast), reflector and shielding are all important factors in determining:

   (a) type and sensitivity of detection instrumentation required;

   (b) if airborne survey equipment is to be used the altitude and speed of survey aircraft and the width of survey intervals needs to be specified; and

   (c) time constraints imposed by decaying source term.

2. <u>What is the chemical or alloy composition of the fuel?</u>

   This information will enable decisions to be made regarding likelihood of fine dispersion or distribution of sizeable parts of original fuel assemblies. If a wide dispersion of the fuel has occurred, then the problem would be one of general contamination of large

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tracts of land and the requirement for extensive environmental monitoring of flora and fauna. If discrete chunks of fuel have been released then the problem would be one of inadvertent over-exposure of individuals.

3. What is the decaying characteristic of the reactor fuel?

This information will assist in determining how rapidly the search must be conducted to ensure locating any radioactive debris before it decays to a level below which it could be readily detected.

4. What shielding was used?

Information on reactor shielding will contribute to a better understanding of the above-listed questions, and the likelihood of burn-up on re-entry.

5. Was there any other container which might have provided some protection?

Information on protective barriers will also facilitate a better understanding of the likelihood of large-size components surviving the re-entry.

6. If the satellite had come to earth in the Soviet Union what would the Soviet authorities have looked for (type of material, energy level and spectrum of ionizing radiation)? Over what size of geographical area would it have been distributed?

This advice would enable the Canadian search and recovery program to be properly planned and executed including the avoidance of any unnecessary actions or

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duplication of effort. It would enable the most suitable airborne detection equipment to be selected and used, and would assist in identification of contacts (as to whether or not they could be from the satellite.)

7. <u>Is the reactor the same as or essentially similar to 'ROMASHKA' reactor described in IAEA Atomic Energy Review Vol. 9, Nr. 2, 1971 by Pushkarsky and Okhotik?</u>

If the reply to this question is 'Yes', reference to this published information would provide many of the answers to the foregoing questions or at least enough information to enable Canadian scientists to make good estimates of the answers.

Ottawa, February 8, 1978

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№ 18

Посольство Союза Советских Социалистических Республик свидетельствует свое уважение Министерству Иностранных дел Канады и, ссылаясь на ноту Министерства от 8 февраля 1978 года, в которой, в частности, указывается, что на территории Канады обнаружены части космического объекта, являющиеся, "как предполагается", составными частями советского спутника "Космос-954", имеет честь сообщить следующее.

Советская сторона принимает к сведению информацию об обнаруженных на территории Канады предметах и их описание и выражает канадской стороне признательность за эту информацию. Одновременно советская сторона с сожалением отмечает, что поиски и эвакуация упомянутых предметов были осуществлены без участия советских специалистов, хотя советская сторона, руководствуясь нормами и принципами международного космического права, незамедлительно предложила Канаде, в случае обнаружения на ее территории каких-либо разрушившихся частей спутника "Космос-954", срочную помощь в ликвидации возможных последствий падения таких частей и их эвакуации. Не может не вызывать сожаления и тот факт, что официальное уведомление советской стороне об обнаружении на территории Канады предметов, которые, как предполагает канадская сторона, являются частями

В МИНИСТЕРСТВО ИНОСТРАННЫХ ДЕЛ КАНАДЫ

г.Оттава

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спутника "Космос-954", сделано две недели спустя с момента прекращения существования спутника и значительно позже того, как информация об этих предметах стала достоянием прессы и экспертов из других стран.

Посольство уполномочено заявить, что сами по себе предметы, о которых идет речь в ноте Министерства от 8 февраля с.г., интереса для советской стороны не представляют, и соответственно канадская сторона может и в дальнейшем поступать с ними по своему усмотрению. Информируя об этом, Посольство пользуется случаем подчеркнуть, что во всех вопросах, связанных с прекращением существования спутника "Космос-954" над северной частью Канады, советская сторона руководствуется международными соглашениями, регулирующими деятельность государств в космосе.

Посольство Союза Советских Социалистических Республик пользуется этим случаем, чтобы возобновить Министерству Иностранных дел Канады уверения в своем высоком уважении.

г.Оттава, "20" февраля 1978 года.

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Unofficial translation

The Embassy of the Union of Soviet Socialist Republics in Canada presents its compliments to the Department of External Affairs of Canada and, with reference to the Department's note of February 8,1978 which in particular, intimates that parts of a cosmic object were found on Canadian territory which are presumed to be component parts of the Soviet Cosmos-954 satellite, has the honour to communicate the following.

The Soviet side notes the information about the objects discovered on the Canadian territory and their description and expresses gratitude to the Canadian side for this information. At the same time the Soviet side regrets to note that the search and removal of the said objects were carried out without participation of Soviet specialists though the Soviet side, guided by the rules and principles of international cosmic law, immediately offered urgent assistance to Canada, in case some fragments of the Cosmos-954 satellite are discovered on its territory, in liquidation of possible consequences of the fall of such fragments, and in their evacuation. Likewise one cannot but express regret with regard to the fact that the official notification of the Soviet side about the discovery on Canadian territory of objects which are presumed by the Canadian side to be fragments of the Cosmos-954 satellite was made two weeks after the time the satellite ceased to exist and considerably later the information about these objects had been made available to the press and experts from other countries.

The Embassy is authorized to state that the objects mentioned in the Department's note of February 8,1978 do not present interest to the Soviet side as such and,

TO THE DEPARTMENT OF EXTERNAL AFFAIRS OF CANADA
Ottawa

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consequently, the Canadian side can continue to dispose with them at its own discretion. While informing about this, the Embassy takes the opportunity to emphasize that the Soviet side in all questions with regard to the cessation of existence of the Cosmos-954 satellite over the Northern part of Canada, is guided by international agreements regulating the activities of states in the outer space.

The Embassy of the Union of Soviet Socialist Republics avails itself of this opportunity to renew to the Department of External Affairs the assurances of its highest consideration.

Ottawa, February 20, 1978

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No. FLO-0497

The Department of External Affairs presents its compliments to the Embassy of the Union of Soviet Socialist Republics and has the honour to refer to the Embassy's Note of February 20, 1978 concerning the impact of component parts of the Soviet Cosmos 954 satellite on Canadian territory on January 24, 1978.

The Department of External Affairs notes with appreciation the Soviet offer of assistance in the elimination of possible consequences of the presence of fragments of the satellite, and in their evacuation. Canada continues to be gravely concerned about the risk of harmful effects from fragments of the satellite, some of which have been found to be highly radioactive. Search and recovery operations are continuing with a view to locating additional fragments. It is now expected that the search by air and on the ground will continue through the coming weeks and into the summer months.

In this regard, Canada has requested the assistance of the Soviet authorities in furnishing information about the nature and characteristics of the nuclear core contained in the

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satellite. These requests have been conveyed on several occasions, particularly in the Canadian Aide-Mémoire of February 8. The Canadian authorities regret that they have not to date received answers to these questions. Additional information in this regard would be the most helpful form of assistance which could be provided to support ongoing efforts to locate radioactive and hazardous fragments and thus eliminate further consequences and harmful effects of such fragments. Such information would also be invaluable in assessing potential long-range dangers.

In addition to this assistance, the Canadian authorities also wish to discuss with the Soviet authorities other forms of possible assistance. For example, Canada may at an appropriate stage request the USSR to eliminate possible danger and harm from materials of a hazardous and deleterious nature by removing such materials from Canada. Such a request would be in response to the Soviet offer of assistance and would also fall within the framework of the obligations assumed by the USSR under relevant international agreements, including Article 5(4) of the 1968 Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, to which both Canada and the USSR are parties.

The Canadian authorities welcome the Embassy's assurances that in all questions regarding the Cosmos 954 satellite the Soviet Union is guided by international agreements regulating the

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activities of states in outer space. In this regard, the Department of External Affairs wishes to inform the Embassy of the USSR that the Government of Canada will submit to the USSR a claim for damages, including search and recovery costs incurred by Canada as a result of the presence on Canadian territory of hazardous component parts of the Soviet satellite. Continuing search and recovery operations are needed to mitigate or prevent further damages such as possible injury to persons, damage to property and contamination of the environment and to restore the territory to the condition in which it existed before the damage occurred. This claim will be in accordance with international law and relevant international agreements, including the 1972 Convention on International Liability for Damage caused by Space Objects, to which both Canada and the USSR are parties. Since the necessary search and recovery operations are still underway, the full amount of damages are not yet known. The claim will be submitted in due course.

As further component parts are located and identified, the Embassy will be informed.

The Department of External Affairs avails itself of this opportunity to renew to the Embassy of the Union of Soviet Socialist Republics the assurances of its highest consideration.

OTTAWA, 28 February 1978

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No. FLO-0532

The Department of External Affairs presents its compliments to the Embassy of the Union of Soviet Socialist Republics and has the honour to refer to the Department's Note to the Embassy dated February 8, 1978 concerning the impact of component parts of the USSR satellite Cosmos 954 on Canadian territory on January 24, 1978.

In accordance with Article 5, paragraph 1 of the 1968 Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, the Government of Canada wishes further to notify the Government of the Union of Soviet Socialist Republics that, as a result of continuing search and recovery operations, additional component parts, as described in the attached annex, have been located in Canada's Northwest Territories. All of these parts were found to be radioactive.

As further component parts are located and identified, the Government of the Union of Soviet Socialist Republics will be informed.

The Department of External Affairs avails itself of this opportunity to renew to the Embassy of the Union of Soviet Socialist Republics the assurances of its highest consideration.

OTTAWA, 3 March 1978

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<u>Annex to Note No. FLO-0532 of March 3, 1978</u>

1. **<u>Search Area One: at the eastern end of Great Slave Lake, near Fort Reliance, N.W.T.</u>**

   <u>Part No. 6:</u>

   Description: solid, cylindrical shape, approximately 10 cm long, 2 cm in diameter, shiny metallic grey colour blackened at one end, emitting man-made radiation (25 Roentgens per hour at contact).

   Location: 62°56.5' N. 109°08' W.

   <u>Part No. 7:</u>

   Description: solid, cylindrical shape, approximately 10 cm long, 2 cm in diameter, shiny metallic grey colour blackened at one end, emitting man-made radiation (30 Roentgens per hour at contact).

   Location: 62°56' N. 109°08.4' W.

   <u>Part No. 8:</u>

   Description: large, oval shaped, slightly curved metal flake, approximately 5 cm at longest point, emitting man-made radiation (10 Roentgens per hour at contact).

   Location: 62°43' N. 109°59' W.

   <u>Part No. 9:</u>

   Description: solid, cylindrical shape, approximately 10 cm long, 2 cm in diameter, emitting man-made radiation (10 Roentgens per hour at contact).
   Location: 62°27' N. 110°42' W.

   <u>Part No. 10:</u>

   Description: solid, cylindrical shape, approximately 9 cm long, 2 cm in diameter, emitting man-made radiation (100 milli-Roentgens per hour at one meter).

   Location: 62°53.5' N. 109°26' W.

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Part No. 11:

Description: three flakes, emitting man-made radiation (activity of cluster 100 milli-Roentgens per hour at one meter).

Location: 62°52' N. 109°33' W.

2. Search Area Two: vicinity of Artillery Lake, N.W.T.

Part No. 1:

Description: solid, cylindrical shape, approximately 10 cm long, 2 cm in diameter, bright, unburned reflective surface, emitting man-made radiation (50 Roentgens per hour at contact).

Location: 62°58' N. 108°57' W.

Part No. 2:

Description: solid, cylindrical shape, approximately 10 cm long shiny metallic colour, emitting man-made radiation (25 Roentgens per hour at contact).

Location: 62°59' N. 108°55' W.

Part No. 3:

Description: solid, cylindrical shape, approximately 10 cm long, 2 cm in diameter, bright reflective surface, slightly charred, emitting man-made radiation (100 Roentgens per hour at contact).

Location: 63°00.5' N. 108°51' W.

3. Search Area Nine: south-east of Great Slave Lake, N.W.T.

Part No. 1:

Description: about fifty small particles of less than 1 cm diameter, recovered in area approximately 4 miles west of Snowdrift, N.W.T., emitting man-made radiation (varying from 1 to 3 Roentgens per hour at contact).

Location: 62°36' N. 110°46' W. area

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4. **Search Area Ten: south-east of Great Slave Lake, N.W.T.**

Part No. 1:

Description: solid, black cube, 1 cm, emitting man-made radiation (500 Roentgens per hour at contact).

Location: $62^{\circ}22'$ N. $111^{\circ}40'$ W.

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№ 27

Посольство Союза Советских Социалистических Республик свидетельствует свое уважение Министерству Иностранных дел Канады и имеет честь сослаться на ноты Министерства от 28 февраля и 3 марта 1978 года.

Советская сторона принимает к сведению переданную ей информацию об обнаруженных на территории Канады II предметах, которые канадская сторона считает разрушившимися частями спутника "Космос-954", и выражает канадской стороне признательность за эту информацию. Посольство уполномочено вновь заявить, что сами по себе эти предметы интереса для советской стороны не представляют и соответственно канадская сторона может поступать с ними по своему усмотрению.

В связи с обращением канадской стороны с просьбой о дополнительных сведениях относительно находившейся на борту спутника "Космос-954" энергоустановки Посольство хотело бы напомнить, что канадской стороне уже была передана необходимая информация о спутнике, которая, по мнению советской стороны, достаточна для организации и проведения эффективных поисков возможных последствий прекращения его существования над территорией Канады. Идя, однако, навстречу пожеланиям канадской стороны и стремясь оказать ей действенную помощь, советская сторона дополнительно сообщает следующее.

В МИНИСТЕРСТВО ИНОСТРАННЫХ ДЕЛ КАНАДЫ
Оттава

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Энергоустановка спутника "Космос-954" представляла собой обычный ядерный реактор, работавший на уране, обогащенном изотопом урана-235. Характеристики распада использовавшегося топлива обычные для реактора, прекратившего свою работу. Активная зона реактора представляла собой сборку из тепловыделяющих элементов с бериллиевым отражателем. Конструкция реактора предусматривала разрушение отражателя при входе в плотные слои атмосферы, после чего должно произойти полное разрушение активной зоны реактора.

Посольство вновь подтверждает, что во всех вопросах, связанных с прекращением существования спутника "Космос-954", советская сторона руководствуется международными соглашениями, регулирующими деятельность государств в космосе. Если канадская сторона имеет намерение предъявить претензию о компенсации за ущерб, который мог быть причинен в результате прекращения существования спутника "Космос-954" над северной частью Канады, советская сторона как участник конвенции 1972 года о международной ответственности за ущерб, причиненный космическими объектами, рассмотрит вопрос о таком ущербе в строгом соответствии с положениями указанной Конвенции.

Посольство пользуется настоящим случаем, чтобы возобновить Министерству Иностранных дел Канады уверения в своем высоком уважении .

г. Оттава, "21" марта 1978 года.

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Unofficial [illegible]

N° 27

The Embassy of the Union of Soviet Socialist Republics presents its compliments to the Department of External Affairs of Canada and has the honour to refer to the Department's notes of February 28 and March 3, 1978.

The Soviet side takes note of the information transmitted to it about 11 objects discovered on the territory of Canada which are believed by the Canadian side to be disintegrated parts of the Cosmos-954 satellite, and is grateful to the Canadian side for this information. The Embassy is authorized to state once again that those objects as such do not present interest to the Soviet side and accordingly the Canadian side can deal with them at its own discretion.

In connection with the request made by the Canadian side for additional information regarding the power unit which was on board the Cosmos-954 satellite, the Embassy would remind that the necessary information about the satellite was already made available which, in the opinion of the Soviet side, is sufficient to organize and carry out effective search for possible consequences of its cessation of existence over Canadian territory. However, trying to meet the wishes of the Canadian side and render it real assistance the Soviet side communicates the following.

The power unit of the Cosmos-954 satellite was an ordinary nuclear reactor working on uranium enriched with isotope of uranium-235. Fuel decay data are the usual ones for a reactor that ceased its work. The reactor's active zone was a set of heat-emitting elements with a berillium reflector.The reactor's design provided for destruction of the reflector at the entry into dense layers of the atmosphere to be followed by the total destruction of the reactor's active zone.

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The Embassy reaffirms that the Soviet side is guided in all questions with regard to the cessation of existence of the Cosmos-954 satellite by the international agreements regulating the activities of states in the outer space. If the Canadian side has intention to present a claim of compensation for damage which may have been caused as a result of the cessation of existence of the Cosmos-954 satellite over the Northern part of Canada, the Soviet side, as a party to the 1972 Convention on international liability for damage caused by cosmic objects, will consider the question of such damage in strict accordance with the provisions of that Convention.

The Embassy avails itself of this opportunity to renew to the Department of External Affairs the assurances of its highest consideration.

Ottawa, March 21st, 1978.

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Note No. FLO-0840

The Department of External Affairs presents its compliments to the Embassy of the Union of Soviet Socialist Republics and has the honour to refer to the Embassy's Note No. 27 of March 21, 1978.

The Canadian authorities have carefully reviewed the information contained in the Embassy's Note of March 21. In order to discharge their responsibilities for the health and safety of persons and the environment in the area affected by the impact of the Cosmos 954 satellite, the Canadian authorities would appreciate additional information on the quantity, nature and characteristics of all materials in the satellite likely to be toxic or radioactive, including activity from fission products or due to neutron activation which have reached or might have reached the surface of the earth following the break-up of the satellite.

In order to conduct the recovery operation in a manner as effective as possible, it will be important to have information on the mass balance, to assist in determining how much can be accounted for on the earth's surface in Canada and how much was dissipated in the atmosphere. It is assumed that originally the satellite consisted of several tonnes of satellite material and several tens of kilograms of reactor core. To date the Canadian

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authorities have recovered only approximately 100 kgs of material, some as relatively large pieces and some as fine particles.

The Canadian authorities accordingly request replies to the following questions:

1. Twenty-nine cylinders of beryllium, about 10 cm long by 2 cm diameter, have been found. These each present a gamma-field of about 25 R/hr near contact, and the gamma-spectrum of several cylinders showed the presence of fission products on the surface. These cylinders are therefore of potential hazard to persons and those found have been removed.

   What was the total number of beryllium cylinders of this kind originally present in the satellite?

2. Six beryllium cylinders, about 25 cm long by 9.5 cm diameter, have been found, each presenting a gamma-field of about 10 R/hr on contact. While their density indicates that they may be solid beryllium, they appear to have threaded or welded end caps.

   How many of these cylinders were present in the satellite, and are they all solid?

3. Are there any other pieces made of beryllium which may have survived re-entry? What was the total amount of beryllium in such pieces present in the satellite?

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4. Small spheres (0.5 mm or so in diameter, 2.5 milligrams in weight) and small flakes, both composed of a uranium-molybdenum mixture with gamma fields up to about 1 R/hr near contact, have been found over an area of many thousand square kilometers. The wide scattering of such particles imposes serious concern about potential human and environmental hazards. In order to assist in the recovery and clean-up operation, more information is required on the nature, composition and mass of the core.

   Was the core a uranium-molybdenum alloy as indicated by the fragments found? What was the total mass of uranium and of molybdenum used in the reactor?

5. Do the Soviet authorities have any information on the solubility of the uranium-molybdenum alloy; of the fission products formed during reactor operation; or of compounds formed during re-entry, and of their possible up-take into the food chain?

6. What other materials of potential hazard to persons and to the environment originating in the satellite should be anticipated and what quantity of them might be found on the surface of Canada, in view of the failure of the satellite to burn up completely on re-entry, as planned?

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The Department wishes to emphasise the importance which the Canadian authorities attach to receiving this information, which would be of great assistance in the conduct of the ongoing search and recovery operations and for the maximum protection of persons and property in the areas affected. In view of the highly technical nature of these questions, the Department proposed on March 3 that there should be a meeting of technical experts on both sides at the earliest opportunity. The Department wishes to reiterate the invitation for the Soviet authorities to send one or more technical experts knowledgeable in areas covered by these questions to visit Ottawa for discussions with experts of the Atomic Energy Control Board of Canada.

The Department of External Affairs avails itself of this opportunity to renew to the Embassy of the Union of Soviet Socialist Republics the assurances of its highest consideration.

OTTAWA, 13 April 1978

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Посольство СССР свидетельствует свое уважение МИД Канады и имеет честь сослаться на ноту Министерства от 13 апреля 1978 г.

Советская сторона с пониманием относится к проявляемой канадской стороной заботе об охране здоровья и безопасности населения в районе, над которым 24 января 1978 г. прекратил свое существование спутник "Космос-954". Именно этими соображениями руководствовалась советская сторона, передавая канадской стороне информацию о спутнике, которая, по мнению советской стороны, необходима и достаточна для эффективного поиска и оценки возможных последствий прекращения его существования над территорией Канады. Стремясь оказать канадской стороне дальнейшую помощь, советская сторона внимательно изучила сведения и соображения, содержащиеся в ноте МИД Канады от 13 апреля 1978 г., и с учетом этого хотела бы довести до сведения канадской стороны следующее.

Как уже сообщалось канадской стороне, активная зона реактора спутника "Космос-954" представляла собой сборку из тепловыделяющих элементов на основе обогащенного урана-235 с

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бериллиевым отражателем. Других материалов, представляющих потенциальную опасность для людей и окружающей среды, на спутнике не имелось. Что касается использовавшихся в реакторе элементов из бериллия, то в случае их сохранения после аэродинамического воздействия и падения на землю уровень создаваемого ими внешнего облучения без длительного непосредственного контакта не представляет опасности для людей и окружающей среды. В состав бериллиевого отражателя входили шесть подвижных элементов, уже найденных вами, и несколько десятков вкладышей цилиндрической формы, большинство из которых вами обнаружены. Возможность выпадения на землю всех вкладышей, входивших в состав бериллиевого отражателя, после разрушения активной зоны реактора исключается.

Все материалы активной зоны реактора и конструкционных элементов спутника обладают малой растворимостью, и в случае их выпадения на поверхность земли включение их в пищевые цепочки практически исключается.

Советская сторона лишена возможности изложить какие-либо соображения относительно вероятного района рассеивания разрушившихся частей спутника, поскольку мы, к сожалению, не располагаем информацией о прямых траекторных измерениях конечного участка его вхождения в плотные слои атмосферы.

В целом, по оценке советских специалистов, информация, переданная до настоящего времени

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канадской стороной, показывает, что радиационную обстановку на всей обследованной территории по уровню внешнего облучения можно было бы признать практически безопасной для населения. В аналогичных условиях на территории Советского Союза дальнейшие поиски были бы, очевидно, прекращены. Исходя из этого, вызывает сомнение целесообразность организации специальной встречи советских и канадских технических экспертов для продолжения обсуждения поставленных канадской стороной вопросов, поскольку советские специалисты могли бы изложить по ним только ту информацию, которая уже известна канадской стороне. Советская сторона считает также необходимым отметить, что некоторые из поставленных канадской стороной вопросов явно относятся к информации, выходящей за пределы того объема, который необходим для обеспечения охраны здоровья и безопасности людей и окружающей среды.

Посольство пользуется настоящим случаем, чтобы возобновить МИД Канады уверения в своем высоком уважении.

Оттава, "31" мая 1978 года

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No. 57

The Embassy of the USSR presents its compliments to the Department of External Affairs and has the honour to refer to the Department's note of April 13,1978.

The Soviet side regards with understanding the Canadian side's concern for the health and safety of population in the area over which the "Cosmos-954" satellite ceased to exist on January 24, 1978. Those were the considerations which guided the Soviet side when it communicated to the Canadian side the information about the satellite which, in the Soviet side's opinion, is necessary and sufficient for effective search and evaluation of possible consequences of its cessation of existence over the Canadian territory. Seeking to render further assistance to the Canadian side, the Soviet side has carefully examined the information and considerations contained in the Department's note of April 13, 1978 and consequently would communicate the following.

As the Canadian side has already been informed, the reactor core of the "Cosmos-954" satellite was a set of heat-emitting elements based on enriched uranium-235 with a beryllium reflector. There were no other materials on board potentially hazardous to persons and the environment. As to the beryllium elements used in the reactor, the level of the external radiation emmitted by them, should they survive the aerodynamic effect and reach the surface, does not present hazard to persons or the environment without prolonged immediate contact. The beryllium reflector included six moving elements that have already been found by you, and several tens of rods of cylindrical form, most of which were discovered. The probability of all those rods in the reflector reaching the surface after the reactor's core disintegrated, is excluded.

TO THE DEPARTMENT OF EXTERNAL AFFAIRS
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All the materials of the core and the structural elements of the satellite are of low solubility and in case of fall to the surface their up-take into the food chain is practically excluded.

The Soviet side is not in a position to offer any considerations regarding probable area of dispersion of the satellite's fragments for, unfortunately, we do not have information on immediate trajectory measurements of the final part of its entry in dense layers of the atmosphere.

In general, in the Soviet specialists' estimation, the information transmitted up until present by the Canadian side indicates that the radiation situation over the entire examined territory judging by the level of external radiation could be recognized as practically safe for population. In similar conditions further search on the Soviet Union's territory would evidently be discontinued. In view of this, the expediency of organizing a special meeting of Soviet and Canadian technical experts to continue discussion of the questions posed by the Canadian side would seem doubtful since the Soviet specialists would be able to state the information which is already known to the Canadian side. The Soviet side finds it also necessary to note that some of the questions put by the Canadian side obviously relate to the information which is outside the scope of the amount necessary to secure health and safety of persons and the environment.

The Embassy avails itself of this opportunity to renew to the Department of External Affairs the assurances of its high condideration.

Ottawa, May 31 , 1978.

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No. FLO-2884

The Department of External Affairs presents its compliments to the Embassy of the Union of Soviet Socialist Republics and has the honour to refer to the Department's Notes to the Embassy dated February 8 and March 3, 1978 concerning the impact of component parts of the USSR satellite Cosmos 954 on Canadian territory on January 24, 1978.

In accordance with Article 5, paragraph 1, of the 1968 Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, the Government of Canada wishes further to notify the Government of the Union of Soviet Socialist Republics that the Canadian authorities have now ended their search and recovery operations and that the component parts located by the Canadian authorities since the start of these operations, including the parts described in the above-mentioned Notes, are listed in the

... attached annex.

The Department of External Affairs avails itself of this opportunity to renew to the Embassy of the Union of Soviet Socialist Republics the assurances of its highest consideration.

OTTAWA, December 18, 1978

The Embassy of the Union of
Soviet Socialist Republics,

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ANNEX

LOCATION	DESCRIPTION
1. 63°47.8'N 104°13.5'W	6 Metal struts, each approximately 1 metre long attached to flexible metal plate.
2. Area bounded by: 63°09'N 108°03'W 63°15'N 108°03'W 63°20'N 106°55'W 63°27'N 106°55'W	6 Beryllium cylinders, approximately 25 cm long x 10 cm diameter. Man made radiation.
3. Area bounded by: 62°27'N 111°30'W 62°33'N 111°30'W 63°04'N 108°18'W 63°00'N 108°18'W	41 Beryllium rods approximately 10 cm long x 2.5 cm. Man made radiation.
4. Area bounded by: 61°31'N 114°50'W 61°50'N 114°50'W 61°45'N 109°00'W 63°00'N 109°00'W	6 metallic plates 1 piece of sheath-like material 18 small flakes, slivers, and chunks. All man-made radiation.
5. 62°52.2'N 109°39.2'W	1 metallic cylinder Approximately 51 cm maximum length, 36 cm diameter, 2.5 mm thick wall, non radioactive.

In addition to the above items of debris, approximately 4000 particles were found, distributed over a wide area, south and east of the trajectory over Great Slave Lake, extending a short distance into Saskatchewan and also into Northern Alberta.

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A N N E X   A

STATEMENT OF CLAIM

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STATEMENT OF CLAIM

INTRODUCTION

1. This Statement sets forth Canada's claim for compensation for damage the result of the intrusion into Canadian air space of a Soviet space object, the Cosmos 954 satellite, and the deposit on Canadian territory of hazardous radioactive debris from the satellite. The claim is presented pursuant to the 1972 Convention on International Liability for Damage caused by Space Objects and the international practice of states. The Statement outlines the facts giving rise to the claim, the legal principles applicable to the claim, the compensation claimed and certain reservations entered by Canada.

THE FACTS

2. The Soviet space object, the Cosmos 954 satellite, hereinafter also referred to as the satellite, was placed in orbit by the Union of Soviet Socialist Republics on September 18, 1977. The Secretary-General of the United Nations was officially informed of the launching, as reported in United Nations document No. A/AC.105/INF. 368 of November 22, 1977. According to the Note of March 21, 1978 of the Embassy of the Union of Soviet Socialist Republics in Ottawa, the satellite carried on board a "... nuclear reactor working on uranium enriched with isotope of uranium-235". On January 24, 1978, the satellite entered the earth's atmosphere intruding into Canadian air space at about 11:53 A.M. Greenwich Mean Time to the north of the Queen Charlotte Islands on the west coast of Canada. On re-entry and disintegration, debris from the satellite was deposited on Canadian territory, including portions of the Northwest Territories, Alberta and Saskatchewan.

3. Within minutes of the re-entry and the intrusion of the satellite into Canadian air space the Government of the United States of America made an offer of technical and matériel assistance to assist Canadian emergency operations. This offer of assistance was accepted immediately by the Government of Canada.

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4. In the course of the day January 24, 1978, an official of the Department of External Affairs expressed to the Ambassador of the Union of Soviet Socialist Republics in Ottawa the surprise of the Government of Canada that the Government of the Union of Soviet Socialist Republics had failed to give Canada notice of the possible re-entry of the satellite into the earth's atmosphere in the region of Canada and subsequently, of the imminent re-entry of the satellite. The Canadian official put questions to the Ambassador concerning the satellite and, noting information as to the presence of a nuclear reactor on board the satellite, requested that precise responses be provided urgently. The questions posed on that occasion were reiterated on January 27, 1978 and are recorded in the Department of External Affairs Aide-Memoire of February 8, 1978 presented to the Embassy.

5. Later on January 24, 1978, the Ambassador of the Union of Soviet Socialist Republics advised an official of the Department of External Affairs that the satellite had been expected to enter the dense layers of the atmosphere on January 24, 1978 and, in case it did not burn out completely in the atmosphere, the possibility that some of its parts would fall in the area of the Aleutian Islands was not excluded. The Ambassador asserted that there should not be any sizeable hazard and that in places of impact there could only be insignificant local pollution requiring very limited measures of disactivation. He also stated that the construction of the nuclear reactor on board the satellite envisaged its complete destruction on re-entry of the satellite into the dense layers of the atmosphere. On that occasion, the Ambassador expressed his Government's readiness to render urgent assistance by sending to Canada a group of specialists to ameliorate the possible consequences and evacuate remnants of the satellite. Canadian officials replied that their urgent need was for immediate and complete answers to the questions posed earlier on January 24, 1978.

6. In the Note of March 21, 1978, the Embassy informed the Department of External Affairs that the active zone of the nuclear reactor on board the satellite "... was a set of heat-emitting elements with a berillium reflector" and that "The reactor's design provided for destruction of the reflector at the entry into dense layers of the atmosphere to be followed by the total destruction of the reactor's active zone".

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7. The Government of the Union of Soviet Socialist Republics failed to provide timely and complete replies to the questions posed by Canada on January 24, 1978 despite the reiteration of the request for information on several occasions, in particular in the Department of External Affairs' Aide-Memoire of February 8, 1978, in its Note of February 28, 1978 to the Embassy and in its Note of April 13, 1978 to the Embassy. The Government of Union of Soviet Socialist Republics ultimately provided some information in the Notes of the Embassy dated March 21, 1978 and May 31, 1978. This information, particularly that in the latter Note, contributed to the Canadian evaluation of the required course of action.

8. Upon the intrusion of the satellite into Canadian air space and with the apprehension of the deposit of hazardous radioactive debris from the satellite on Canadian territory, the Canadian Armed Forces and the Atomic Energy Control Board of Canada undertook operations directed at locating, recovering, removing and testing the debris and cleaning up the affected areas. The purpose of these operations was to identify the nature and extent of the damage caused by the debris, to limit the existing damage and to minimize the risk of further damage and to restore to the extent possible the affected areas to the condition that would have existed if the intrusion of the satellite and the deposit of the debris had not occurred. The operations took place in two phases: Phase I from January 24, 1978 to April 20, 1978 and Phase II from April 21, 1978 to October 15, 1978. The total cost incurred by the various Canadian Departments and Agencies involved in Phase I of the operations was $12,048,239.11 of which $4,414,348.86 are included in Canada's claim. The total cost incurred during Phase II of the operations was $1,921,904.55 of which $1,626,825.84 are included in Canada's claim. In sum, Canada claims from the Union of Soviet Socialist Republics payment in the amount of $6,041,174.70.

9. During the operations described in paragraph 8, debris from the satellite was found in areas of the Northwest Territories and the Provinces of Alberta and Saskatchewan. Lists describing the location of the debris are set forth in annexes to the Department of External Affairs Notes dated February 8, 1978, March 3, 1978 and December 18, 1978, to the Embassy of the Union of Soviet Socialist Republics. Inscriptions in the Cyrillic alphabet can be distinguished on one of the fragments recovered.

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10. The Canadian authorities determined that all but two of the fragments recovered were radioactive. Some fragments located proved to be of lethal radioactivity. It was necessary for the debris to be handled with great care as it is well established that radioactive material can have serious physiological effects and in some cases can be fatal. The debris recovered was sent to the Canadian Government's Whiteshell Nuclear Research Establishment at Pinawa, Manitoba. There tests were carried out on the debris, the results of which provided valuable information that was of assistance with regard to the operations and confirmed that highly radioactive and dangerous debris from the satellite had been deposited on Canadian territory.

11. The Government of Canada informed the Secretary-General of the United Nations of the discovery of debris from the satellite as is indicated in United Nations documents A/AC.105/214 and 214/Corr.1 of February 8, 1978; A/AC.105/217 of March 6, 1978 and A/AC.105/236 of December 22, 1978.

12. In addition to general admissions as to the origin of the Cosmos 954 satellite, the Government of the Union of Soviet Socialist Republics confirmed the Canadian conclusion as to the origin and identity of the recovered debris by admissions contained in the statement made on February 14, 1978 in the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space by Academician Fedorov, a representative of the Union of Soviet Socialist Republics. In addition, the Note from the Embassy of the Union of Soviet Socialist Republics in Ottawa dated May 31, 1978 includes admissions to the effect that debris found in the Northwest Territories of Canada originated from the satellite.

13. It is thus beyond doubt on the basis of the operations described above and on the basis of admissions by representatives of the Union of Soviet Socialist Republics that the debris found in the areas covered by the operations originated from the Soviet space object identified as the Cosmos 954 satellite.

THE LAW

14. Canada's claim is based jointly and separately on (a) the relevant international agreements and in particular the 1972 Convention on International Liability for Damage caused by Space Objects, to which both Canada and the Union of Soviet Socialist Republics are parties, and (b) general principles of international law.

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(a) International Agreements

15. Under Article II of the Convention on International Liability for Damage caused by Space Objects, hereinafter also referred to as the Convention, "A launching State shall be absolutely liable to pay compensation for damage caused by its space object on the surface of the earth...." The Union of Soviet Socialist Republics, as the launching State of the Cosmos 954 satellite, has an absolute liability to pay compensation to Canada for the damage caused by this satellite. The deposit of hazardous radioactive debris from the satellite throughout a large area of Canadian territory, and the presence of that debris in the environment rendering part of Canada's territory unfit for use, constituted "damage to property" within the meaning of the Convention.

16. The intrusion into Canadian air space of a satellite carrying on board a nuclear reactor and the break-up of the satellite over Canadian territory created a clear and immediate apprehension of damage, including nuclear damage, to persons and property in Canada. The Government of the Union of Soviet Socialist Republics failed to give the Government of Canada prior notification of the imminent re-entry of the nuclear powered satellite and failed to provide timely and complete answers to the Canadian questions of January 24, 1978 concerning the satellite. It thus failed to minimize the deleterious results of the intrusion of the satellite into Canadian air space.

17. Under general principles of international law, Canada had a duty to take the necessary measures to prevent and reduce the harmful consequences of the damage and thereby to mitigate damages. Thus, with respect to the debris, it was necessary for Canada to undertake without delay operations of search, recovery, removal, testing and clean-up. These operations were also carried out in order to comply with the requirements of the domestic law of Canada. Moreover, Article VI of the Convention imposes on the claimant State a duty to observe reasonable standards of care with respect to damage caused by a space object.

18. The operations described in paragraph 8 above would not have been necessary and would not have been undertaken had it not been for the damage caused by the hazardous radioactive debris from the Cosmos 954 satellite on Canadian territory and the reasonable apprehension of further damage in view of the nature of nuclear contamination. As a result of these operations, the areas affected have been restored, to the extent possible, to the condition which would have existed if the intrusion of the satellite and the deposit of the debris

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had not occurred. The Departments and Agencies of the Government of Canada involved in these operations incurred, as a result, considerable expense, particularly with regard to the procurement and use of services and equipment, the transportation of personnel and equipment and the establishment and operation of the necessary infrastructure. The costs included by Canada in this claim were incurred solely as a consequence of the intrusion of the satellite into Canadian air space and the deposit on Canadian territory of hazardous radioactive debris from the satellite.

19. In respect of compensation for damage caused by space objects, the Convention provides for "... such reparation in respect of the damage as will restore ... /the claimant/ to the condition which would have existed if the damage had not occurred" (Article XII). In accordance with its Preamble, the Convention seeks to ensure "... the prompt payment .../under its terms/ of a full and equitable measure of compensation to victims of such damage" (Fourth preambular paragraph). Canada's claim includes only those costs which were incurred in order to restore Canada to the condition which would have existed if the damage inflicted by the Cosmos 954 satellite had not occurred. The Convention also provides that "The compensation which the launching State shall be liable to pay for damage under this Convention shall be determined in accordance with international law and the principles of justice and equity..." (Article XII). In calculating the compensation claimed, Canada has applied the relevant criteria established by general principles of international law and has limited the costs included in its claim to those costs that are reasonable, proximately caused by the intrusion of the satellite and deposit of debris and capable of being calculated with a reasonable degree of certainty.

20. The liability of the Union of Soviet Socialist Republics for damage caused by the satellite is also founded in Article VII of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, done in 1967, and to which both Canada and the Union of Soviet Socialist Republics are parties. This liability places an obligation on the Union of Soviet Socialist Republics to compensate Canada in accordance with international law for the consequences of the intrusion of the satellite into Canadian air space and the deposit on Canadian territory of hazardous radioactive debris from the satellite.

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(b) General Principles of International Law

21. The intrusion of the Cosmos 954 satellite into Canada's air space and the deposit on Canadian territory of hazardous radioactive debris from the satellite constitutes a violation of Canada's sovereignty. This violation is established by the mere fact of the trespass of the satellite, the harmful consequences of this intrusion, being the damage caused to Canada by the presence of hazardous radioactive debris and the interference with the sovereign right of Canada to determine the acts that will be performed on its territory. International precedents recognize that a violation of sovereignty gives rise to an obligation to pay compensation.

22. The standard of absolute liability for space activities, in particular activities involving the use of nuclear energy, is considered to have become a general principle of international law. A large number of states, including Canada and the Union of Soviet Socialist Republics, have adhered to this principle as contained in the 1972 Convention on International Liability for Damage caused by Space Objects. The principle of absolute liability applies to fields of activities having in common a high degree of risk. It is repeated in numerous international agreements and is one of "the general principles of law recognized by civilized nations" (Article 38 of the Statute of The International Court of Justice). Accordingly, this principle has been accepted as a general principle of international law.

23. In calculating the compensation claimed, Canada has applied the relevant criteria established by general principles of international law according to which fair compensation is to be paid, by including in its claim only those costs that are reasonable, proximately caused by the intrusion of the satellite and deposit of debris and capable of being calculated with a reasonable degree of certainty.

COMPENSATION CLAIMED

24. On the basis of the facts asserted and the legal principles referred to herein, the Government of Canada claims payment from the Government of the Union of Soviet Socialist Republics of the sum of $6,041,174.70.

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RESERVATIONS

25. The Government of Canada hereby enters reservations as follows:

(a) The Government of Canada reserves its right to present additional claims for compensation to the Government of the Union of Soviet Socialist Republics in respect of damage not yet identified or determined or damage which may occur in the future as a result of the intrusion of the Cosmos 954 satellite into Canada's air space and the deposit of hazardous radioactive debris from the satellite on Canadian territory;

(b) The Government of Canada reserves its right to claim from the Government of the Union of Soviet Socialist Republics all costs that Canada may be obliged to incur in the event of the establishment of a Claims Commission under the provisions of the 1972 Convention on International Liability for Damage caused by Space Objects and the presentation by Canada of its claim to such a Claims Commission; and

(c) The Government of Canada reserves its right to claim from the Government of the Union of Soviet Socialist Republics payment of interest at an appropriate rate on the amount of compensation declared payable by a Claims Commission, such interest to accrue from the date of the decision or award of the Claims Commission.

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ANNEX C

SCHEDULE OF COSTS

PHASE I

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TABLE OF COSTS INCURRED BY THE PARTICIPATING DEPARTMENTS OF THE GOVERNMENT OF CANADA IN THE SEARCH AND RECOVERY OPERATION FOR THE COSMOS 954 SATELLITE FROM JANUARY 24, 1978 TO APRIL 20, 1978 INCLUSIVE

	DEPARTMENT	INCREMENTAL COSTS	TOTAL COSTS
1.	Atomic Energy Control Board	$433,627.40	$496,254.03
2.	Energy, Mines and Resources	$254,564.14	$295,871.80
3.	National Defence	$3,706,765.30	$11,223,549.32
4.	National Health and Welfare	$8,759.11	$18,031.11
5.	Royal Canadian Mounted Police	$10,632.91	$14,532.85
	TOTAL:	$4,414,348.86	$12,048,239.11

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IN THE MATTER OF A CLAIM FOR COMPENSATION PRESENTED BY CANADA TO THE SOVIET UNION FOR DAMAGES INCURRED AS A RESULT OF THE INTRUSION ON CANADIAN TERRITORY ON JANUARY 24, 1978 OF THE COSMOS 954 SATELLITE LAUNCHED BY THE SOVIET UNION

AFFIDAVIT OF JOHN MCMANUS

I, JOHN MCMANUS, of the City of Ottawa, of the Province of Ontario, public servant, MAKE OATH AND SAY AS FOLLOWS:

1. On January 24, 1978, I was employed in the position of Director, Planning & Administration Branch of the Atomic Energy Control Board, an agency of the Canadian Government, and since that time have been and still am in the same position and as such I have knowledge of the matters hereinafter deposed.

2. In that position my regular duties include: being aware of expenditures incurred by the Board; being shown the invoices and other business records which document the amounts owed for services and materials rendered to the Board; being responsible for the necessary steps to determine if these invoices and business records accurately reflect the amounts owed for services and materials rendered to the Board; being certain that payments are made to the persons and the companies who have submitted the invoices and other business records for these services and materials rendered to the Board; and, being responsible

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for the administration of the salary expenditures to the employees of the Board.

3(1) Since January 24, 1978, the Board has been actively involved in the search and recovery operation for the debris from the Cosmos 954 Satellite.

In the performance of my duties as Director, Planning and Administration Division, I work closely with officers of the Board and am directly involved in the control of the expenditures of the Board in respect of the said search and recovery operation. These officers and myself are working in the same premises and in fact on the same floor and are in daily contact with each other.

I was personally aware of the situation created by this intrusion of the Cosmos 954 as I had to authorize the expenditures for the said search and recovery operation.

On the basis of the accounts, invoices, and daily contact with the officers involved, I had knowledge of the nature of the operation which is more particularly described in the Schedule to this affidavit.

3.(2) I have read the text of the Schedule, and have initialed each page of the said document. The facts and figures mentioned thereto, in respect of the Board's operation and involvement correspond, to my knowledge, to the situation as confirmed by the approved expenditures,

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the accounts and invoices which I have reexamined within the last few days immediately preceeding the signature of this affidavit.

4. The total amount spent by the Board to May 23, 1978 inclusive in the search and recovery operation was 459,912.19 dollars, exclusive of salaries.

These expenditures have been divided in two parts. The first part covers the period between January 24, 1978 and April 20, 1978 and the second part, the period between April 21st and May 23rd 1978. The April 20th date has been chosen on the basis of the total cost incurred and to be incurred by the Government of Canada and relates to the withdrawal of Canadian Armed Forces support for the other Government agencies, including this Board, responsible for this operation. May 23rd has been chosen for practical reason as the most latest date acceptable for the preparation of this affidavit and ongoing calculation of expenses.

The salaries have been calculated separately as they are divided on an incremental basis and total basis, as such a distinction in costs does not apply, in so far as the Board is concerned to all the other expenditures incurred on account of the intrusion of the debris of the Cosmos 954. The total amount paid in salaries from January 24 to May 23, 1978 inclusive is 125,236.09 dollars.

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These expenditures were incurred as indicated on the Schedule.

5. The accounts, vouchers, receipts and other records relating to these expenses are in possession of the Board under my control, at the City of Ottawa.

6. Other expenditures have been incurred by the Board after May 24, 1978 relatively to the same matter but such expenditures are not included in these documents.

SWORN BEFORE ME IN THE CITY)
OF OTTAWA, IN THE REGIONAL)
MUNICIPALITY OF OTTAWA -)
CARLETON THIS 25 DAY OF)
AUGUST, A.D. 1978)

J.N. LaBarre
A Commissioner, etc.

John McManus

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Schedule to affidavit of J. McManus
sworned on August 25, 1978

Cosmos 954 - Phase I

1. Atomic Energy Control Board Organization

1.1 Conventional Requirements

The AECB was constituted in 1946 by the Atomic Energy Control Act, primarily for the control and supervision of the development, application and use of atomic energy, and to enable Canada to participate in measures of international control that might be agreed upon. At that time the emphasis was on the control of strategically important materials, but since then numerous applications of nuclear energy and of radioisotopes have been developed. The broad functions of the AECB over the years have evolved into a comprehensive licensing system covering all aspects of nuclear energy and prescribed substances, in the interests of health, safety and security. In January 1978, the full-time permanent staff of the AECB numbered 148, all involved in (or supporting) the licensing of facilities or radioisotope uses, in compliance activities to ensure that licence conditions are being followed, in identifying and arranging for research to support or justify licence requirements, and in developing health and safety standards. Thus staff consists of engineers, scientists, health physicists and appropriate support personnel.

1.2 Requirements Introduced by Cosmos 954

When remnants of Cosmos 954 reached the earth in northern Canada, the AECB as the only appropriate Canadian agency was requested to assume lead responsibility for aspects of search and recovery related in any way to radiation, health and safety of people and the environment. The AECB was also given the further authority to cover the costs incurred by all departments other than DND, in this program.

Since the AECB is a relatively small body the number of experts available for an emergency such as Cosmos 954 introduced is limited. To adequately staff the needs in the search areas, the AECB was obliged to call upon the help of other organizations for expertise. At peak, essentially all the AECB health physicist staff were deeply involved and most of the compliance (radiation

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surveyor and radioisotope inspector) staff were likewise. Many of the AECB's regular functions, especially compliance inspection but also research projects, were seriously interfered with as staff covered the requirements of the search and recovery.

Furthermore, the major radioactivity clean-up programs in Port Hope and elsewhere were interrupted as staff and equipment were borrowed. In order to avoid complete abrogation of some aspects of its responsibilities, at a time when the public and the nuclear industry are calling for more intensive protective efforts, the AECB had no alternative but to borrow staff from others as mentioned.

It was necessary to send experts from Ottawa to the area because none exist there; the AECB has no regional offices in Western Canada. Experts from other departments also came from Ottawa. This entailed travelling expenses, with living costs at commercial hotels while on site. Since there are few roads in the search area and those only in the Southwest section, search, travel and recovery in most of the region was required to be air-borne. (DND supplied the aircraft services) To land in open tundra or lake areas required either helicopter or ski-plane. One winter air strip was prepared at the east end of the region to simplify supplying field ground forces living in tents. Between 24 January and 26 April AECB staff on a rotational base with support from other departments manned the Edmonton Headquarters, the Yellowknife office and search and recover teams flying in the search area. Because of the urgency of locating fragments and of removing them to a safe holding site, hours were irregular and large amounts of overtime were worked. With no detailed knowledge of the type of satellite or reactor the only safe assumption to make, once radioactive debris had been located, was that it should be sought on the ground and removed as quickly as possible.

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Although most of the main searches were based in Yellowknife, at various times men and equipment were also based in Baker Lake, at Warden's Grove ("Cosmos Lake") on the Thelon River, and at several of the communities on the south shore of Great Slave Lake. A location in Cape Dorset, Baffin Island, where it was suspected that a part of the satellite had fallen, was also investigated by a party on the ground over a ten-day period. These requirements naturally led to a division of equipment and expertise that made staffing and supply even more difficult.

Maximum AECB staff at Edmonton/Yellowknife at any one time was 13. The average over the period January 24 to 20 April was 8 men. This number was augmented by secondments from other departments or agencies possessing suitable staff, including Atomic Energy of Canada Limited and Defence Research Establishment Ottawa - both of these had from 1 to 3 men in the field most of the time. The Geological Survey of Canada maintained up to four scientists and air-borne search experts at Edmonton, and National Health and Welfare and Fisheries and Environment sent one or two men to the area for special purposes. Actions of all of these other departments were coordinated by AECB as the lead agency, and supported by DND as needed in respect to travel in the area, air search time and transportation.

2. Equipment

When Cosmos 954 landed there was a sudden dearth of appropriate equipment for searches that proceeded by air at different elevations, and on the ground in frequented places.

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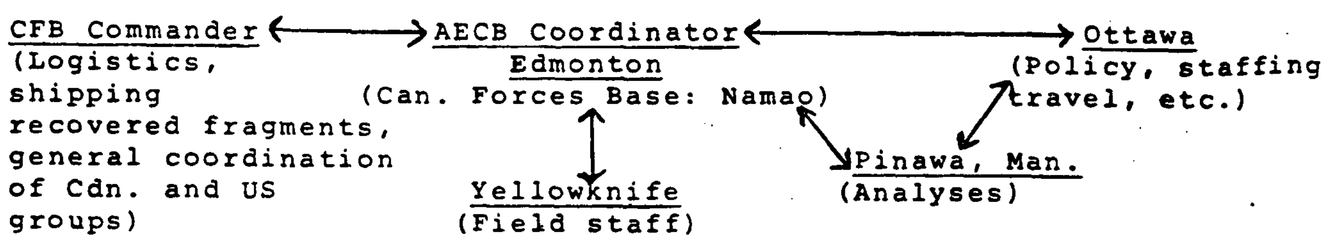
The US team was able to provide some equipment, but only temporarily; DND's nuclear clean-up forces had more, but not the most suitable and not enough. The Geological Survey provided top-calibre air-borne detection equipment and this was latterly supported by contracted commercial exploration equipment. Computer services were purchased from the University of Alberta to support the air-borne search. The AECB robbed ongoing clean-up programs of portable equipment, again only a temporary expedient. Thus to meet the demands of a search that covered thousands of square miles from the air, and a number of communities, roads, etc., on the ground by detailed foot-surveys, additional detection instrumentation was immediately sought. Without it the search would have been much less successful in the Phase I time period.

Once radioactive material was found, proper containers for handling, storage and shipping were required. The available supply of containers was very quickly exhausted as fragments were discovered in the trajectory zone and recovered, and rush fabrication of a suitable supply was necessary. The special safety features of the containers made them very expensive.

Occurrence and nature of debris finds were recorded by very complete photographic records for evidence purposes.

3. Organization of Operation

With headquarters provided by DND at Canadian Forces Base, Namao (near Edmonton), the search and recovery organization from the AECB viewpoint, developed as follows:



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The AECB coordinator in Edmonton was the senior AECB man in the area. In Edmonton he was supported by scientific advisors (1-3), a transportation advisor, a health physics/radiation advisor, an instrument specialist (part of the time), a clerk-typist, and members of DND's Nuclear Accident Survey Team (NAST). Some of the above were on loan to AECB from AECL and DREO, and for part of the time DSTI personnel were also present.

In Yellowknife, a field coordinator was supported by three radiation protection specialists (for field recovery and community surveys), and members of NAST.

At the temporary camp on the Thelon River ("Cosmos Lake") a health physicist and a radiation specialist under AECB aegis were present, as well as US and DND personnel.

At Pinawa, the AECB maintained an analytical advisor during the peak recovery and analysis period; actually this position was filled by DREO scientists on rotation.

At Cape Dorset, 1 radiation protection expert was on hand for about ten days, supported by an NRC ice expert over a three day period.

In Ottawa a Steering Group, headed by DND and participated in by other involved federal agencies, met frequently to learn of the latest situation and to expedite policy decisions to meet changing conditions and requirements in the search area. The Steering Group communicated continuously with its representatives in the west.

Given the organization developed in a hurry for the NWT operations, the almost complete lack of information on what to expect in the way of residual fragments of satellite structures and reactor materials, the meteorological and climatic conditions of the area and the season, and the divided authority between DND and AECB, the decision-making process was one of expediency. For the most part the people actively involved in the search and recovery were those best able to see the need for policy and planning changes. The fact that a large contingent of high-level and experienced US scientific and search personnel was present,

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unavoidably introduced a complicating factor into decisions, even recognizing the valuable assistance of the US team.

4. Modus Operandi

Given the trajectory of fall, the area was divided into segments for search. The search activities were operated by DND in military aircraft. The search teams, including those operating on foot in communities, included DND, AECB, AECL, GSC and US personnel. Search patterns were agreed upon in joint discussions, before teams were sent out. Air-borne searches lasted as long as twelve hours out of Yellowknife.

Airborne detection of radioactivity required first, a means of identifying the location, next, discrimination between natural and artificial (satellite fragment) radiation, and third, ability to land and recover the material. The first two involved very sophisticated airborne equipment and capability of spectral analysis (such as provided by the GSC), to distinguish uranium ore radiation from fission production radiation and sensitive portable equipment for final location on the ground.

Ground surveys in communities and other frequented areas were carried out by teams armed with sensitive radiation detectors. Streets and often houses were checked on foot. When radioactive material was located, it was collected with rigorous care in an appropriate container, and at the end of the day containers were flown back to Namao for temporary storage in a bunker made available by DND, pending escorted shipment to Winnipeg and thence to AECB at Pinawa. Material recovered from the broader airborne searches was handled similarly.

Search and recovery personnel wore photographic badges for periodic development by DNHW to record degree of exposure to radiation, and urine samples from early recovery teams were monitored for tritium by DNHW. Personnel regularly checked clothing, equipment and aircraft for contamination, and any signs of this were immediately tracked down and eliminated.

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7. Costs

Costs as requested are presented here in two parts: those incurred prior to 21 April, and those coming on or after 21 April. This division is an arbitrary one and it should be realized that many expenditures that were cleared after 21 April represent costs incurred prior to that date. Thus, all costs post-21 April do not neatly refer to"Phase II" of the Cosmos 954 Search and Recovery Program.

7.1 Prior to 21 April, 1978

7.1.1 Travel

Costs of travelling from Ottawa to Edmonton, Yellowknife and Pinawa, and for accomodation on site, are summarized in ANNEX I, based on expense accounts paid by AECB in the period.

Additional travel charges, billed directly to AECB, are given in ANNEX II.

7.1.2 Transportation of equipment & samples

Costs of shipping equipment to the field are given in ANNEX III. DND covered costs of almost all sample shipments from Edmonton to Winnipeg, where they were taken to Pinawa by AECL truck, for which costs are included in the AECL bill (ANNEX IV).

7.1.3 Professional and Temporary Services

Costs for such services are summarized in ANNEX IV. The computer services were required to support Geological Survey airborne detection surveys. The AECL bill includes costs of analysis, salaries, sample transport (Winnipeg Airport to Pinawa), handling and storage.

7.1.4 Rentals

ANNEX V shows costs of personal paging service devices, which were needed to ensure that key personnel could be contacted quickly, & a telecopier so that data could be received without delay from Pinawa and from Edmonton.

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7.1.5 Materials & Supplies

ANNEX VI lists materials and supplies purchased to operate field offices, and particularly items required to ensure proper identification and recording of samples for evidence record purposes. The photographic bill is an example of this aspect of records.

7.1.6. Equipment

Radiation measuring equipment and approved containers for handling and shipping radioactive materials required to be purchased to meet the needs of expanding search and recovery operations. Costs of these (as billed prior to 20 April 1978) are given in ANNEX VII.

7.1.7 Other Expenditures

Other expenditures are given in ANNEX VIII. Radiation warning signs were prepared in Inuit and one of the Indian written languages. "Nu-con Smears" represent standard swipes for checking for contamination on containers, etc.

7.2 Post 21 April, 1978

7.2.1 Expenditures since 21 April and up to 24 May, 1978, are presented in the same order:

Travel - ANNEX IX. The National Research Council bill is for travel and living expenses of an ice expert at Cape Dorset, Baffin Island.

Transportation-ANNEX X.

Professional and Special Services ANNEX-XI

Rentals-ANNEX XII.

Materials and Supplies-ANNEX XIII.

Equipment-ANNEX XIV. Many of the charges represent equipment ordered prior to 21 April, but also some of this equipment was purchased in order to be able to equip properly the new search teams of Phase II.

Other Expenditures-ANNEX XV.

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8. Salaries

Salaries for those involved in Operation Morning Light from 24 January to 20 April, are given in ANNEX XVI. This tabulation also shows the cost of recorded overtime, and the dollar equivalent of this.

ANNEX XVII gives salaries for personnel involved between 21 April and 23 May. In this period there was no overtime work recorded.

WKG: 1-VI-78

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ANNEX I

TRAVEL (Ottawa to Edmonton, Yellowknife, Pinawa, and Return as Needed)

The total travel cost incurred by A.E.C.B. in connection with Operation Morning Light for the period January 24 - April 20, 1978 is $44,213.56, a figure that represents the total of related expense accounts in the period.

The total travel cost incurred by A.E.C.B. for the period April 21 to the present is $1,548.11.

The toal average cost to maintain an A.E.C.B. employee in Edmonton for a 2 week period for Operation Morning Light:

Pre-20 April		Post-20 April	
Airfare Edmonton Return	$354.00		$354.00
Meals (14 day period) and Incidental (rates to Mar. 31, 1978)	265.00	Meals (14 day period) and Incidental (new rates effective April 1, 1978)	272.00
Accomodation (14 nights at an average of $24.00 per night)	336.00		336.00
	$955.00		$962.00

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Cosmos 954 - Expenses from January 24 - April 20, 1978

ADDITIONAL TRAVEL CHARGES (EDMONTON AND YELLOWKNIFE-DIRECT BILLINGS)

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Pine Point Hotel	Accomodation in Pine Point for AECB staff member(s)	20/3/78	$ 245.20
Avis	Car rental for AECB staff. (W. Courneya)	23/3/78	346.43
Avis	Car rental for AECB staff. (W. Courneya)	23/3/78	211.52
Tilden	Car rental for AECB staff. (Dr. R. Eaton)	10/4/78	1,020.00
Ptarmigan Inn	Accomodation in Yellowkinfe for AECB staff.	18/4/78	117.01
	SUB-TOTAL		1,940.16

ANNEX II

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[redacted]

Cosmos 954 - Expenses from January 24 - April 20, 1978

TRANSPORTATION

Name of Supplier	Product or Service Supplied	Date Paid	Amount
CP Air	Charges for shipment of equipment	31/3/78	$ 36.65
CP Express	Charges for shipment of equipment	10/4/78	27.25
CN	Charges for shipment of equipment	10/4/78	71.15
Air Canada Cargo	Charges for shipment of equipment	14/4/78	330.00
CN	Charges for shipment of equipment	14/4/78	84.50
	SUB-TOTAL		$ 549.55

ANNEX III

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Cosmos 954 - Expenses from January 24 - April 20, 1978

PROFESSIONAL & SPECIAL SERVICES (including Temporary Service)

Name of Supplier	Product or Service Supplied	Date Paid	Amount
University of Alberta	Computing Services to support Morning Lite Operation	13/4/78	$ 2,440.11
Atomic Energy of Can. Ltd.	Analytical work done at WNRE & cost of personnel from CRNL.	20/3/78– 18/4/78	260,437.16*
D. Kemp Edwards	Asbonite Sheet	7/3/78	6.24
D. Kemp Edwards	Asbonite Sheet	16/3/78	6.24
Office Overload	Temporary assistance in office in Edmonton	7/3/78	218.50
"	"	16/3/78	413.25
"	"	20/3/78	413.25
"	"	29/3/78	394.25
"	"	5/4/78	308.75
"	"	10/4/78	232.75
Health & Welfare Canada	Film Service Photo Detection	31/3/78	1,122.00
	SUB-TOTAL		$265,992.50

*This sum comprises the following:

Salaries	$164,621.76
Analytical Services	69,760.00
Travel	13,190.53
Materials & Supplies	7,811.13
Contracts	3,068.73
Vehicle mileage	840.00
Vehicle rental	32.58
Express charges	27.00
Overhead	1,085.43
TOTAL	$260,437.16

ANNEX IV

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Cosmos 954 - Expenses from January 24 - April 20, 1978

RENTALS

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Beeper Co. Ltd.	Monthly Rental of Radio Pager NEC. - insurance	17/2/78 7/3/78	$ 110.00
Xerox Ltd.	Rental of Xerox 410 - Telecopier	20/3/78 16/4/78	236.90
A.E.C.L. Comm. Products	Container rentals	7/3/78	100.00
	SUB-TOTAL		$ 446.90

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COSMOS 954 - Expenses from January 24 - April 20,1978

MATERIALS AND SUPPLIES

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Camera House	Film for photographic equipment	17/2/78	$ 34.68
Cal Cop	Acetate Transparency	07/3/78	8.00
Safety Supply	WTT300 Tru Touch Gloves - Disposal gloves	29/3/78	44.40
Wallacks	Clear Acetate Water Soluble Pens	17/3/78	37.45
Wallacks	Transparent Ruler (24")	03/4/78	2.40
Robert E. Cole Co.	Kim-Pack Embossed No. 6361	17/2/78	38.08
Ken Anderson Office Supp.	Packing Pockets	17/3/78	77.45
Xerox	Paper for Telecopier	20/3/78	33.75
Cal Cop	Labels	07/3/78	175.00
Lomor Printers	Tags ("Radioactive Material", Contaminated)	17/3/78	200.20
Northwest Color Labs Ltd.	Contract developing film	07/3/78 10/4/78	11,491.77
McBain Camera Ltd.	Camera Filters	11/4/78	20.95
Uncle Bens' Sporting Goods	Kerosene Model	11/4/78	48.00
Lomor Printers	Labels ("Radioactive")	17/3/78 03/4/78	469.97
		SUB TOTAL:	$12,682.10

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Cosmos 954 - Expenses from January 24 - April 20, 1978

EQUIPMENT

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Superior Electronics	Beta Gamma radiation Survey Meter	20/3/78	$ 9,811.20
Datamex	Contamination Dector equipped with mounted speaker and 5 foot cables	10/4/78	5,969.00
Roctest Ltd.	Saphymo-Stel Scintillometre Type S.P.P. 2NF	7/3/78	4,351.20
Datamex	Eberline Sample Holder Model SH-4	17/3/78	900.00
Datamex	Hand Probe (EBERLINE) with cable - Model HP-210	17/3/78	1,980.00
Datamex	Personal Air Sampler & Filter Paper	17/3/78	6,120.00
A.E.C.L. Comm. Products	F-112, F-113, F-239 containers	7/3/78	13,078.80
A.E.C.L. Comm. Products	Containers Type F-113	7/3/78	11,592.00
	SUB-TOTAL		$ 53,802.20

ANNEX VII

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Cosmos 954 - Expenses from January 24 - April 20, 1978

ALL OTHER EXPENDITURES

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Mr. Joe Toby	Translation services for A.E.C.B. signs	23/2/78	$ 45.00
Datamex	Nu-con Smears	7/3/78	575.00
	SUB-TOTAL		$ 620.00
	TOTAL		$380,246.97

ANNEX VIII

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TRAVEL

Name of Supplier	Product or Service Supplied	Date Paid	Amount
			$
N.R.C.	Charges for travel expenses of N.R.C. personnel	24/4/78	836.71
A.E.C.L. (Pinawa, Manitoba)	Charges for travel expenses of A.E.C.L. and A.E.C.B. staff	11/5/78	211.40
	SUB-TOTAL		$ 1048.11

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Cosmos 954 - Expenses from April 21 - present

TRANSPORTATION

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Superior Electronics	Freight charges for shipment of equipment	2/5/78	$ 579.00
Air Canada Expedair	"	2/5/78	44.00
"	"	15/5/78	55.00
Purolator Courier	Charges related to shipment of supplies to Edmonton	25/4/78	12.00
	SUB-TOTAL		$ 690.00

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Cosmos 954 - Expenses from April 21 - present

PROFESSIONAL & SPECIAL SERVICES

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Dr. M.J. Apps	Gamma Spectroscopic Analysis of five samples	25/4/78	$ 50.00
University of Alberta	Analysis of Samples from Cosmos Lake and Cape Dorset	15/5/78	300.00
Dr. L. Wiebe (University of Alberta)	Tritium analysis consulting services	25/4/78	250.00
Office Overload	Temporary staff for Edmonton A.E.C.B. office	2/5/78	394.25
"	"	"	394.25
	SUB-TOTAL		$ 1388.50

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Cosmos 954 - Expenses from April 21 - present

RENTALS

Name of Supplier	Product or Service Supplied	Date Paid	Amount
A.E.C.L. Comm. Products	Rental of F-233 #3 Containers	26/4/78	$ 86.00
	SUB-TOTAL		$ 86.00

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COSMOS 954 - Expenses from April 21 - present

MATERIALS AND SUPPLIES

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Lomor Printers	Radioactive Labels	26/4/78	$ 63.00
A.E.C.L. Commercial Products	Gaskets for container F-112 and F-113 and shipping charges	26/4/78	243.40
Shippers' Supply	Kim-Pack	02/5/78	77.20
Safety Supply Company	Radiation Hazard Signs	11/5/78	31.00
A.E.C.L. Commercial Products	5 gallon pails with lids and ring clamps	03/5/78	217.00
Northwest Color Labs	Contract for developing film	28/4/78 16/5/78	2,625.90
Southam Printing	Printing Films	24/4/78	7.00

SUB TOTAL: $3,264.50

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Cosmos 954 - Expenses from April 21 - present

EQUIPMENT

Name of Supplier	Product or Service Supplied	Date Paid	Amount
A.E.C.L. Comm. Products	4 foot long tongs	24/4/78	$ 36.00
Canadian Tire Corp.	Transistor Battery	15/5/78	15.00
Datamex	Personal Digital Dosimeters - Model Prime-V	3/5/78 15/5/78	10,300.00
Datamex	Eberline Beta Gamma Geiger Counter Eberline Beta Gamma Portable Ion Chamber Survey Meter	26/4/78	11,594.00
Ludlum Measurements	Micro-R-Meters	15/5/78	7,088.00
Datamex	Eberline Portable Gamma Dose Rate Meter Eberline Portable Scaler	3/5/78	9,368.00
Datamex	Eberline Portable Beta Gamma Geiger Counters Eberline Beta Window Pancake Probes with cables	3/5/78	2,790.00
Datamex	Vacuum Cleaner with filters	3/5/78	2,030.00
A.E.C.L. Comm. Products	Steel drums (16 gallon)	25/4/78	1,200.00
Radionics Ltd.	Victoreen Personal Dosimeters	24/4/78	4,700.00
Bond Brass Ltd.	Fabrication of 20 Shipping Containers	25/4/78	10,487.02
Superior Electronics	Berthold end window counter tube with cable and adapter jack	25/4/78	5,402.88
A.E.C.L. Comm. Products	Special 5 gallon pails, steel cables with snaps, caulking and 1 gallon pails	25/4/78	239.50
A.E.C.L. Comm. Products	Special 5 gallon pails, lead bricks, lead sheets	25/4/78	546.70
Provincial Cancer Hospitals Board	Construction of 3 containers for Operation Morning Light	25/4/78	649.82
	SUB-TOTAL		$ 66,446.92

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COSMOS 954 - Expenses from April 21 - present

MATERIALS AND SUPPLIES

Name of Supplier	Product or Service Supplied	Date Paid	Amount
A.E.C.L. (Whiteshell Nuclear Labs)	Storage facilities for samples and debris from Cosmos 954	25/4/78	$3,635.94
W.K. Gummer	Telephone call to P. Kennedy in Cape Dorset	03/5/78	3.73
Border Brokers	Shipment of equipment	26/4/78	1,553.41
		SUB TOTAL:	$5,193.08
		TOTAL:	$79,665.22

(Includes $1548.11
Travel from Annex I)

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ANNEX XVI

Salary Expenditures 24 Jan. to 20 April, 1978

Name	Days Worked A*	Days Worked B	Salaries Regular Days**	Salaries Total
Beaudry	10	18.2	562.00	1584.84
Blackburn	9	11.4	1260.72	2857.63
Boyd	9	11.9	1190.16	2763.81
Brown	11	4.5	1054.02	1485.21
Cahill	21	35	1609.86	4292.96
Cameron	42.8	11.6	4183.27	5317.05
Campbell	36.6	26.7	3693.67	6388.23
Charlebois	34.5	0	1860.24	1860.24
Chatterjee	18	33.3	1776.60	5063.31
Courneya, O.	9	22.4	843.40	2942.80
Courneya, W.	19	38.9	1948.07	5936.48
Davediuk	10	6.7	1181.80	1973.60
Eaton	22	16	2462.24	4252.96
Elagupillai	33	35.5	3255.78	8731.41
Elks	33.9		3118.46	3118.46
Goyette	26	35.8	1913.34	4547.86
Gummer	39.8	0	5405.63	5405.63
Henry	10	0	1069.40	1069.40
Horvath	13	22.7	924.30	2538.27
James	6	15.8	625.56	2272.86
Jennekens	11	9.6	1763.08	3301.76
Kealy	22.1	4.7	1490.86	1807.92
Kennedy	6	3.5	524.34	830.20
Knight	18	9.9	2337.84	3623.65
Marleau	21	23	1674.33	3508.12
McLellan	26	14.9	2591.16	4076.09
Meloche	2.3	0	146.35	146.35
Molloy	17	22.1	629.00	1446.00
Prince	3	0	557.70	557.70
Ricard	15	22.6	1465.20	3672.76
Robertson	18	25.8	1780.02	4331.38
Shultz	23	32.5	2503.78	6041.73
Smythe	6	0	837.00	837.00
Spence	8	0	803.36	803.36
Tallim	9	0	464.04	464.04
Utting	20	25.4	1839.80	4176.34
White	11	6	1280.95	1979.65
			62,626.63	116,007.06

*A - regular working days
 B - overtime credits in days

** Salary for regular working days. The total includes equivalent compensation for overtime credits.

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ANNEX XVII

Salary Expenditures 21 April to 23 May, 1978

Name	Days Worked	Salaries
Cameron	4.5	439.83
Campbell	10.3	1039.48
Charlebois	4.5	242.64
Courneya, W.	2.0	205.06
Davediuk	3.0	354.54
Eaton	14.0	1566.88
Elks	7.0	643.93
Elagupillai	2.0	197.32
Gummer	9.7	1317.45
Kealey	5.0	337.30
Knight	8.0	1039.04
Prince	1.0	185.90
Ricard	14.8	1445.66
Wawrychuk	2.0	214.00
	87.8	9229.03

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IN THE MATTER OF A CLAIM FOR COMPENSATION PRESENTED BY CANADA TO THE SOVIET UNION FOR DAMAGES INCURRED AS A RESULT OF THE INTRUSION ON CANADIAN TERRITORY ON JANUARY 24, 1978 OF THE COSMOS 954 SATELLITE LAUNCHED BY THE SOVIET UNION

AFFIDAVIT OF W.K. GUMMER

I, W.K. Gummer of the City of Ottawa, of the Province of Ontario, public servant, MAKE OATH AND SAY AS FOLLOWS:

1. On January 24, 1978, I was employed in the position of Manager, Planning and Coordination Division of the Atomic Energy Control Board, an agency of the Canadian Government, and since that time have been and still am in the same position.

2. While in that position I became Coordinator of Board activities in connection with the clean-up (search and recovery) operation following the fall to earth of Cosmos 954 in the Northwest Territories and my duties included:

- ensuring that Board and other department staff were kept up to date on search and recovery program developments.
- serving as contact for Board and other personnel who were in the field.
- advising Board and field officers on program requirements and changes.

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3. Between January 24, 1978 and April 20, 1978 the Board was actively involved in the search and recovery operation for the debris from the Cosmos 954 Satellite.

In the performance of my duties as Coordinator of the search and recovery operation, I work closely with officers of the Board involved in the said search and recovery operation. These officers and myself are working in the same premises and are in daily contact with each other.

As the Coordinator, I was personally aware of the situation created by this intrusion of the Cosmos 954 as I had to coordinate the effort of officers of the Board and other government agencies in respect of the said search and recovery operation.

4. On the basis of information obtained in the performance of my duties, I prepared the document attached hereto as a Schedule.

The document describes the main events and facts establishing that previously to the intrusion on Canadian territory on January 24, 1978 of the Cosmos 954 Satellite, the government of Canada, its representatives and responsible agencies were aware of the failure of the satellite to maintain altitude, of the fact that it was nuclear-powered, and of the fact that it might come to earth in Canada; and that following re-entry debris was in fact found in the area where the satellite was seen to have come down, most of this debris being radioactive.

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SWORN BEFORE ME IN THE CITY)
OF OTTAWA, IN THE REGIONAL)
MUNICIPALITY OF OTTAWA -)
CARLETON THIS 18th DAY OF)
Aug A.D. 1978)

J.F.D. MacIsaac
A notary Public in and
for the Province of Ontario

W.K. Gummer

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Schedule to affidavit of W.K. Gummer
sworned on August 18, 1978

WHY CANADA ASSOCIATED RADIOACTIVE MATERIAL FOUND IN NWT WITH COSMOS 954

1. During the autumn of 1977, NORAD's Space Defence Centre in Colorado predicted that Cosmos 954, launched only on September 18, 1977, would fall in April, 1978. By early January it was apparent that re-entry would take place much sooner, in fact January 23 plus or minus two days was predicted. Early on January 24, NORAD reported that the satellite had begun its entry into earth's atmosphere, on a trajectory pointed towards Canada's Queen Charlotte Islands. At 1153 Greenwich time it was reported that debris from the satellite had landed near Great Slave Lake, Northwest Territories, following a descending path that was visually sighted by several residents of the Territories.

The USSR admitted that Cosmos 954 had failed, and that it was not possible to lift the satellite into a much higher orbit, as had been planned in case of emergency, because of failure of a rocket system. The USSR claimed that Cosmos 954 had been so designed that it would completely burn up on re-entry. It also has referred in correspondence to the cessation of existence of Cosmos 954 over Canadian territory (External Affairs translation of Russian reply to questions, dated 31 May, 1978).

It was a matter of record that Cosmos 954 was powered by a nuclear reactor, although the USSR did not provide a full identification of the mass or power level of the reactor.

2. Based on the calculated trajectory, search was commenced on a pathway extending between the east end of Great Slave Lake and Baker Lake near Hudson Bay. It was along this pathway that foreign materials were soon found; these materials included bits of steel plate and tubing, beryllium cylinders and rods, and charred remnants of these and other fragments. Many fragments showed signs of melting and oxidation. All but one recovered fragment exhibited radioactivity, some at very high levels, and representing both activation and fission products. Fragments were found on or near the surface of the snow and ice cover then existing.

3. The single non-radioactive fragment was a section of tubing or piping, charred from assumed re-entry, lying on the frozen surface of Great Slave Lake and spotted visually from an over-flying search plane. Markings on this fragment included Cyrillic lettering.

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4. Canada raised a series of questions with the USSR in an attempt to obtain information on the mass of the nuclear power source, information which would assist in the search and recovery operations if it were known how much core material existed in Cosmos 954. Full information was not made available, but the USSR advised Canada that the full complement of certain beryllium cylinders had been found, and that "most" of "several tens of beryllium rods" had been recovered.

5. All recovered fragments were sent to the Whiteshell Nuclear Research Establishment of Atomic Energy of Canada Limited, at Pinawa, Manitoba. Here, analytical work was carried out to identify material and their radioactivity, so that hazards to health and safety of people and the environment could be recognized and eliminated. Some tiny particles, representing partially burned reactor core, were sent to Ottawa where laboratories of the Department of National Health and Welfare carried out studies of solubility in simulated gastric juices.

Except for some small particles consumed in such analysis, all fragments of Cosmos 954 have been retained at Pinawa under safe storage conditions. They are available for further study or other purposes.

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IN THE MATTER OF A CLAIM FOR COMPENSATION PRESENTED BY CANADA TO THE SOVIET UNION FOR DAMAGES INCURRED AS A RESULT OF THE INTRUSION ON CANADIAN TERRITORY ON JANUARY 24, 1978 OF THE COSMOS 954 SATELLITE LAUNCHED BY THE SOVIET UNION

AFFIDAVIT OF W.K. GUMMER

I, W.K. Gummer of the City of Ottawa, of the Province of Ontario, public servant, MAKE OATH AND SAY AS FOLLOWS:

1. On January 24, 1978, I was employed in the position of Manager, Planning and Coordination Division of the Atomic Energy Control Board, an agency of the Canadian Government, and since that time have been and still am in the same position and as such I have knowledge of the matters hereinafter deposed.

2. While in that position I became Coordinator of Board activities in connection with the clean-up (search and recovery) operation following the fall to earth of Cosmos 954 in the Northwest Territories and my duties included:

- ensuring that Board and other department staffs were kept up to date on search and recovery program developments.
- serving as contact for Board and other personnel who were in the field.
- advising Board and field officers on program requirements and changes.

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3. Between January 24, 1978 and April 20, 1978 the Board was actively involved in the search and recovery operation for the debris from the Cosmos 954 Satellite.

In the performance of my duties as Coordinator of the search and recovery operation, I work closely with officers of the Board involved in the said search and recovery operation. These officers and myself are working in the same premises and are in daily contact with each other.

As the Coordinator, I was personally aware of the situation created by this intrusion of the Cosmos 954 as I had to coordinate the effort of officers of the Board and other government agencies in respect of the said search and recovery operation.

4. I have read the documents attached hereto as Schedule A & B, and have initialed each page of the said document. The facts mentioned thereto, in respect of the Board's operation and involvement correspond, to my knowledge, to the situation as confirmed to me by officers of the Board and other government agencies contacted and documents read while in the performance of my duties, on a day to day basis, as coordinator.

SWORN BEFORE ME IN THE CITY)
OF OTTAWA, IN THE REGIONAL)
MUNICIPALITY OF OTTAWA -)
CARLETON THIS 15th DAY OF)
August A.D. 1978.)

J.F.D. MacIsaac
A notary Public in and
for the Province of Ontario

W.K. Gummer

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Schedule A to affidavit of W.K. Gummer
sworned on August 15, 1978

Cosmos 954 - Phase I

1. Atomic Energy Control Board Organization

1.1 Conventional Requirements

The AECB was constituted in 1946 by the Atomic Energy Control Act, primarily for the control and supervision of the development, application and use of atomic energy, and to enable Canada to participate in measures of international control that might be agreed upon. At that time the emphasis was on the control of strategically important materials, but since then numerous applications of nuclear energy and of radioisotopes have been developed. The broad functions of the AECB over the years have evolved into a comprehensive licensing system covering all aspects of nuclear energy and prescribed substances, in the interests of health, safety and security. In January 1978, the full-time permanent staff of the AECB numbered 148, all involved in (or supporting) the licensing of facilities or radioisotope uses, in compliance activities to ensure that licence conditions are being followed, in identifying and arranging for research to support or justify licence requirements, and in developing health and safety standards. Thus staff consists of engineers, scientists, health physicists and appropriate support personnel.

1.2 Requirements Introduced by Cosmos 954

When remnants of Cosmos 954 reached the earth in northern Canada, the AECB as the only appropriate Canadian agency was requested to assume lead responsibility for aspects of search and recovery related in any way to radiation, health and safety of people and the environment. The AECB was also given the further authority to cover the costs incurred by all departments other than DND, in this program.

Since the AECB is a relatively small body the number of experts available for an emergency such as Cosmos 954 introduced is limited. To adequately staff the needs in the search areas, the AECB was obliged to call upon the help of other organizations for expertise. At peak, essentially all the AECB health physicist staff were deeply involved and most of the compliance (radiation

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surveyor and radioisotope inspector) staff were likewise. Many of the AECB's regular functions, especially compliance inspection but also research projects, were seriously interfered with as staff covered the requirements of the search and recovery.

Furthermore, the major radioactivity clean-up programs in Port Hope and elsewhere were interrupted as staff and equipment were borrowed. In order to avoid complete abrogation of some aspects of its responsibilities, at a time when the public and the nuclear industry are calling for more intensive protective efforts, the AECB had no alternative but to borrow staff from others as mentioned.

It was necessary to send experts from Ottawa to the area because none exist there; the AECB has no regional offices in Western Canada. Experts from other departments also came from Ottawa. This entailed travelling expenses, with living costs at commercial hotels while on site. Since there are few roads in the search area and those only in the Southwest section, search, travel and recovery in most of the region was required to be air-borne. (DND supplied the aircraft services) To land in open tundra or lake areas required either helicopter or ski-plane. One winter air strip was prepared at the east end of the region to simplify supplying field ground forces living in tents. Between 24 January and 26 April AECB staff on a rotational base with support from other departments manned the Edmonton Headquarters, the Yellowknife office and search and recovery teams flying in the search area. Because of the urgency of locating fragments and of removing them to a safe holding site, hours were irregular and large amounts of overtime were worked. With no detailed knowledge of the type of satellite or reactor the only safe assumption to make, once radioactive debris had been located, was that it should be sought on the ground and removed as quickly as possible.

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Although most of the main searches were based in Yellowknife, at various times men and equipment were also based in Baker Lake, at Warden's Grove ("Cosmos Lake") on the Thelon River, and at several of the communities on the south shore of Great Slave Lake. A location in Cape Dorset, Baffin Island, where it was suspected that a part of the satellite had fallen, was also investigated by a party on the ground over a ten-day period. These requirements naturally led to a division of equipment and expertise that made staffing and supply even more difficult.

Maximum AECB staff at Edmonton/Yellowknife at any one time was 13. The average over the period January 24 to 20 April was 8 men. This number was augmented by secondments from other departments or agencies possessing suitable staff, including Atomic Energy of Canada Limited and Defence Research Establishment Ottawa - both of these had from 1 to 3 men in the field most of the time. The Geological Survey of Canada maintained up to four scientists and air-borne search experts at Edmonton, and National Health and Welfare and Fisheries and Environment sent one or two men to the area for special purposes. Actions of all of these other departments were coordinated by AECB as the lead agency, and supported by DND as needed in respect to travel in the area, air search time and transportation.

2. Equipment

In early 1975 the AECB possessed one outmoded Geiger Counter. As the needs for radioactive contamination clean-up and control in Port Hope, Elliot Lake, Bancroft and Uranium City came to light, additional radiation detection equipment was obtained. However, when Cosmos 954 landed there was a sudden dearth of appropriate equipment for searches that proceeded by air at different elevations, and on the ground in frequented places.

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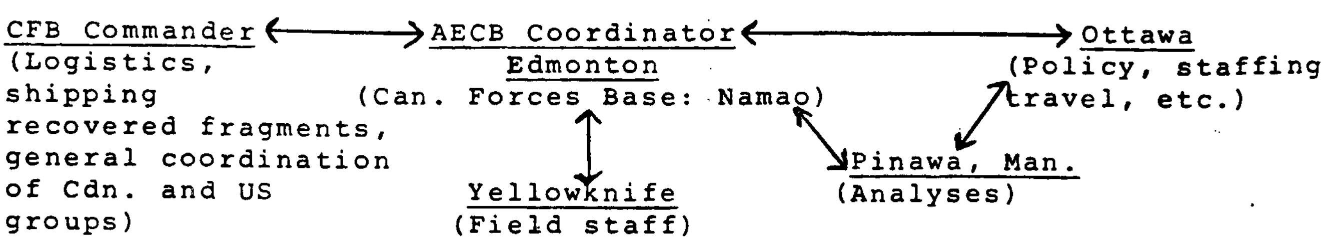
The US team was able to provide some equipment, but only temporarily; DND's nuclear clean-up forces had more, but not the most suitable and not enough. The Geological Survey provided top-calibre air-borne detection equipment and this was latterly supported by contracted commercial exploration equipment. Computer services were purchased from the University of Alberta to support the air-borne search. The AECB robbed ongoing clean-up programs of portable equipment, again only a temporary expedient. Thus to meet the demands of a search that covered thousands of square miles from the air, and a number of communities, roads, etc., on the ground by detailed foot-surveys, additional detection instrumentation was immediately sought. Without it the search would have been much less successful in the Phase I time period.

Once radioactive material was found, proper containers for handling, storage and shipping were required. The available supply of containers was very quickly exhausted as fragments were discovered in the trajectory zone and recovered, and rush fabrication of a suitable supply was necessary. The special safety features of the containers made them very expensive.

Occurrence and nature of debris finds were recorded by very complete photographic records for evidence purposes.

3. Organization of Operation

With headquarters provided by DND at Canadian Forces Base, Namao (near Edmonton), the search and recovery organization from the AECB viewpoint, developed as follows:



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The AECB coordinator in Edmonton was the senior AECB man in the area. In Edmonton he was supported by scientific advisors (1-3), a transportation advisor, a health physics/radiation advisor, an instrument specialist (part of the time), a clerk-typist, and members of DND's Nuclear Accident Survey Team (NAST). Some of the above were on loan to AECB from AECL and DREO, and for part of the time DSTI personnel were also present.

In Yellowknife, a field coordinator was supported by three radiation protection specialists (for field recovery and community surveys), and members of NAST.

At the temporary camp on the Thelon River ("Cosmos Lake") a health physicist and a radiation specialist under AECB aegis were present, as well as US and DND personnel.

At Pinawa, the AECB maintained an analytical advisor during the peak recovery and analysis period; actually this position was filled by DREO scientists on rotation.

At Cape Dorset, 1 radiation protection expert was on hand for about ten days, supported by an NRC ice expert over a three day period.

In Ottawa a Steering Group, headed by DND and participated in by other involved federal agencies, met frequently to learn of the latest situation and to expedite policy decisions to meet changing conditions and requirements in the search area. The Steering Group communicated continuously with its representatives in the west.

Given the organization developed in a hurry for the NWT operations, the almost complete lack of information on what to expect in the way of residual fragments of satellite structures and reactor materials, the meteorological and climatic conditions of the area and the season, and the divided authority between DND and AECB, the decision-making process was one of expediency. For the most part the people actively involved in the search and recovery were those best able to see the need for policy and planning changes. The fact that a large contingent of high-level and experienced US scientific and search personnel was present,

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unavoidably introduced a complicating factor into decisions, even recognizing the valuable assistance of the US team.

4. Modus Operandi

Given the trajectory of fall, the area was divided into segments for search. The search activities were operated by DND in military aircraft. The search teams, including those operating on foot in communities, included DND, AECB, AECL, GSC and US personnel. Search patterns were agreed upon in joint discussions, before teams were sent out. Air-borne searches lasted as long as twelve hours out of Yellowknife.

Airborne detection of radioactivity required first, a means of identifying the location, next, discrimination between natural and artificial (satellite fragment) radiation, and third, ability to land and recover the material. The first two involved very sophisticated airborne equipment and capability of spectral analysis (such as provided by the GSC), to distinguish uranium ore radiation from fission production radiation and sensitive portable equipment for final location on the ground.

Ground surveys in communities and other frequented areas were carried out by teams armed with sensitive radiation detectors. Streets and often houses were checked on foot. When radioactive material was located, it was collected with rigorous care in an appropriate container, and at the end of the day containers were flown back to Namao for temporary storage in a bunker made available by DND, pending escorted shipment to Winnipeg and thence to AECB at Pinawa. Material recovered from the broader airborne searches was handled similarly.

Search and recovery personnel wore photographic badges for periodic development by DNHW to record degree of exposure to radiation, and urine samples from early recovery teams were monitored for tritium by DNHW. Personnel regularly checked clothing, equipment and aircraft for contamination, and any signs of this were immediately tracked down and eliminated.

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7. Costs

Costs as requested are presented here in two parts: those incurred prior to 21 April, and those coming on or after 21 April. This division is an arbitrary one and it should be realized that many expenditures that were cleared after 21 April represent costs incurred prior to that date. Thus, all costs post-21 April do not neatly refer to"Phase II" of the Cosmos 954 Search and Recovery Program.

7.1 Prior to 21 April, 1978

7.1.1 Travel

Costs of travelling from Ottawa to Edmonton, Yellowknife and Pinawa, and for accomodation on site, are summarized in ANNEX I, based on expense accounts paid by AECB in the period.

Additional travel charges, billed directly to AECB, are given in ANNEX II.

7.1.2 Transportation of equipment & samples

Costs of shipping equipment to the field are given in ANNEX III. DND covered costs of almost all sample shipments from Edmonton to Winnipeg, where they were taken to Pinawa by AECL truck, for which costs are included in the AECL bill (ANNEX IV).

7.1.3 Professional and Temporary Services

Costs for such services are summarized in ANNEX IV. The computer services were required to support Geological Survey airborne detection surveys. The AECL bill includes costs of analysis, salaries, sample transport (Winnipeg Airport to Pinawa), handling and storage.

7.1.4 Rentals

ANNEX V shows costs of personal paging service devices, which were needed to ensure that key personnel could be contacted quickly, & a telecopier so that data could be received without delay from Pinawa and from Edmonton.

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7.1.5 Materials & Supplies

ANNEX VI lists materials and supplies purchased to operate field offices, and particularly items required to ensure proper identification and recording of samples for evidence record purposes. The photographic bill is an extreme example of this aspect of records.

7.1.6 Equipment

Radiation measuring equipment and approved containers for handling and shipping radioactive materials required to be purchased to meet the needs of expanding search and recovery operations. Costs of these (as billed prior to 20 April 1978) are given in ANNEX VII.

7.1.7 Other Expenditures

Other expenditures are given in ANNEX VIII. Radiation warning signs were prepared in Inuit and one of the Indian written languages. "Nu-con Smears" represent standard swipes for checking for contamination on containers, etc.

7.2 Post 21 April, 1978

7.2.1 Expenditures since 21 April and up to 24 May, 1978, are presented in the same order:

Travel - ANNEX IX. The National Research Council bill is for travel and living expenses of an ice expert at Cape Dorset, Baffin Island.

Transportation-ANNEX X.

Professional and Special Services-ANNEX XI

Rentals-ANNEX XII.

Materials and Supplies-ANNEX XIII.

Equipment-ANNEX XIV. Many of the charges represent equipment ordered prior to 21 April, but also some of this equipment was purchased in order to be able to equip properly the new search teams of Phase II.

Other Expenditures-ANNEX XV.

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8. Salaries

Salaries for those involved in Operation Morning Light from 24 January to 20 April, are given in ANNEX XVI. This tabulation also shows the cost of recorded overtime, and the dollar equivalent of this.

ANNEX XVII gives salaries for personnel involved between 21 April and 23 May. In this period there was no overtime work recorded.

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ANNEX I

TRAVEL (Ottawa to Edmonton, Yellowknife, Pinawa, and Return as Needed)

The total travel cost incurred by A.E.C.B. in connection with Operation Morning Light for the period January 24 - April 20, 1978 is $44,213.56, a figure that represents the total of related expense accounts in the period.

The total travel cost incurred by A.E.C.B. for the period April 21 to the present is $1,548.11.

The toal average cost to maintain an A.E.C.B. employee in Edmonton for a 2 week period for Operation Morning Light:

Pre-20 April		Post-20 April	
Airfare Edmonton Return	$354.00		$354.00
Meals (14 day period) and Incidental (rates to Mar. 31, 1978)	265.00	Meals (14 day period) and Incidental (new rates effective April 1, 1978)	272.00
Accomodation (14 nights at an average of $24.00 per night)	336.00		336.00
	$955.00		$962.00

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Cosmos 954 - Expenses from January 24 - April 20, 1978

ADDITIONAL TRAVEL CHARGES (EDMONTON AND YELLOWKNIFE-DIRECT BILLINGS)

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Pine Point Hotel	Accomodation in **Pine Point** for AECB staff member(s)	20/3/78	$ 245.20
Avis	Car rental for AECB staff. (W. Courneya)	23/3/78	346.43
Avis	Car rental for AECB staff. (W. Courneya)	23/3/78	211.52
Tilden	Car rental for AECB staff. (Dr. R. Eaton)	10/4/78	1,020.00
Ptarmigan Inn	Accomodation in Yellowkinfe for AECB staff.	18/4/78	117.01
	SUB-TOTAL		1,940.16

ANNEX II

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Cosmos 954 - Expenses from January 24 - April 20, 1978

TRANSPORTATION

Name of Supplier	Product or Service Supplied	Date Paid	Amount
CP Air	Charges for shipment of equipment	31/3/78	$ 36.65
CP Express	Charges for shipment of equipment	10/4/78	27.25
CN	Charges for shipment of equipment	10/4/78	71.15
Air Canada Cargo	Charges for shipment of equipment	14/4/78	330.00
CN	Charges for shipment of equipment	14/4/78	84.50
	SUB-TOTAL		$ 549.55

ANNEX III

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Cosmos 954 - Expenses from January 24 - April 20, 1978

PROFESSIONAL & SPECIAL SERVICES (including Temporary Service)

Name of Supplier	Product or Service Supplied	Date Paid	Amount
University of Alberta	Computing Services to support Morning Lite Operation	13/4/78	$ 2,440.11
Atomic Energy of Can. Ltd.	Analytical work done at WNRE & cost of personnel from CRNL.	20/3/78–18/4/78	260,437.16*
D. Kemp Edwards	Asbonite Sheet	7/3/78	6.24
D. Kemp Edwards	Asbonite Sheet	16/3/78	6.24
Office Overload	Temporary assistance in office in Edmonton	7/3/78	218.50
"	"	16/3/78	413.25
"	"	20/3/78	413.25
"	"	29/3/78	394.25
"	"	5/4/78	308.75
"	"	10/4/78	232.75
Health & Welfare Canada	Film Service Photo Detection	31/3/78	1,122.00
	SUB-TOTAL		$265,992.50

*This sum comprises the following:

Salaries	$164,621.76
Analytical Services	69,760.00
Travel	13,190.53
Materials & Supplies	7,811.13
Contracts	3,068.73
Vehicle mileage	840.00
Vehicle rental	32.58
Express charges	27.00
Overhead	1,085.43
TOTAL	$260,437.16

ANNEX IV

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Cosmos 954 - Expenses from January 24 - April 20, 1978

RENTALS

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Beeper Co. Ltd.	Monthly Rental of Radio Pager NEC. - insurance	17/2/78 7/3/78	$ 110.00
Xerox Ltd.	Rental of Xerox 410 - Telecopier	20/3/78 16/4/78	236.90
A.E.C.L. Comm. Products	Container rentals	7/3/78	100.00
	SUB-TOTAL		$ 446.90

ANNEX V

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COSMOS 954 - Expenses from January 24 - April 20,1978

MATERIALS AND SUPPLIES

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Camera House	Film for photographic equipment	17/2/78	$ 34.68
Cal Cop	Acetate Transparency	07/3/78	8.00
Safety Supply	WTT300 Tru Touch Gloves - Disposal gloves	29/3/78	44.40
Wallacks	Clear Acetate Water Soluble Pens	17/3/78	37.45
Wallacks	Transparent Ruler (24")	03/4/78	2.40
Robert E. Cole Co.	Kim-Pack Embossed No. 6361	17/2/78	38.08
Ken Anderson Office Supp.	Packing Pockets	17/3/78	77.45
Xerox	Paper for Telecopier	20/3/78	33.75
Cal Cop	Labels	07/3/78	175.00
Lomor Printers	Tags ("Radioactive Material", Contaminated)	17/3/78	200.20
Northwest Color Labs Ltd.	Contract developing film	07/3/78 10/4/78	11,491.77
McBain Camera Ltd.	Camera Filters	11/4/78	20.95
Uncle Bens' Sporting Goods	Kerosene Model	11/4/78	48.00
Lomor Printers	Labels ("Radioactive")	17/3/78 03/4/78	469.97
		SUB TOTAL:	$12,682.10

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Cosmos 954 - Expenses from January 24 - April 20, 1978

EQUIPMENT

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Superior Electronics	Beta Gamma radiation Survey Meter	20/3/78	$ 9,811.20
Datamex	Contamination Dector equipped with mounted speaker and 5 foot cables	10/4/78	5,969.00
Roctest Ltd.	Saphymo-Stel Scintillometre Type S.P.P. 2NF	7/3/78	4,351.20
Datamex	Eberline Sample Holder Model SH-4	17/3/78	900.00
Datamex	Hand Probe (EBERLINE) with cable - Model HP-210	17/3/78	1,980.00
Datamex	Personal Air Sampler & Filter Paper	17/3/78	6,120.00
A.E.C.L. Comm. Products	F-112, F-113, F-239 containers	7/3/78	13,078.80
A.E.C.L. Comm. Products	Containers Type F-113	7/3/78	11,592.00
	SUB-TOTAL		$ 53,802.20

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Cosmos 954 - Expenses from January 24 - April 20, 1978

ALL OTHER EXPENDITURES

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Mr. Joe Toby	Translation services for A.E.C.B. signs	23/2/78	$ 45.00
Datamex	Nu-con Smears	7/3/78	575.00
	SUB-TOTAL		$ 620.00
	TOTAL		$380,246.97

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ANNEX VIII

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Cosmos 954 - Expenses from April 21 - present

TRAVEL

Name of Supplier	Product or Service Supplied	Date Paid	Amount
			$
N.R.C.	Charges for travel expenses of N.R.C. personnel	24/4/78	836.71
A.E.C.L. (Pinawa, Manitoba)	Charges for travel expenses of A.E.C.L. and A.E.C.B. staff	11/5/78	211.40
	SUB-TOTAL		$ 1048.11

ANNEX IX

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Cosmos 954 - Expenses from April 21 - present

TRANSPORTATION

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Superior Electronics	Freight charges for shipment of equipment	2/5/78	$ 579.00
Air Canada Expedair	"	2/5/78	44.00
"	"	15/5/78	55.00
Purolator Courier	Charges related to shipment of supplies to Edmonton	25/4/78	12.00
	SUB-TOTAL		$ 690.00

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Cosmos 954 - Expenses from April 21 - present

PROFESSIONAL & SPECIAL SERVICES

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Dr. M.J. Apps	Gamma Spectroscopic Analysis of five samples	25/4/78	$ 50.00
University of Alberta	Analysis of Samples from Cosmos Lake and Cape Dorset	15/5/78	300.00
Dr. L. Wiebe (University of Alberta)	Tritium analysis consulting services	25/4/78	250.00
Office Overload	Temporary staff for Edmonton A.E.C.B. office	2/5/78	394.25
"	"	"	394.25
	SUB-TOTAL		$ 1388.50

ANNEX XI

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Cosmos 954 - Expenses from April 21 - present

RENTALS

Name of Supplier	Product or Service Supplied	Date Paid	Amount
A.E.C.L. Comm. Products	Rental of F-233 #3 Containers	26/4/78	$ 86.00
	SUB-TOTAL		$ 86.00

ANNEX XII

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COSMOS 954 - Expenses from April 21 - present

MATERIALS AND SUPPLIES

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Lomor Printers	Radioactive Labels	26/4/78	$ 63.00
A.E.C.L. Commercial Products	Gaskets for container F-112 and F-113 and shipping charges	26/4/78	243.40
Shippers' Supply	Kim-Pack	02/5/78	77.20
Safety Supply Company	Radiation Hazard Signs	11/5/78	31.00
A.E.C.L. Commercial Products	5 gallon pails with lids and ring clamps	03/5/78	217.00
Northwest Color Labs	Contract for developing film	28/4/78 16/5/78	2,625.90
Southam Printing	Printing Films	24/4/78	7.00

SUB TOTAL: $3,264.10

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ANNEX XIII

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Cosmos 954 - Expenses from April 21 - present

EQUIPMENT

Name of Supplier	Product or Service Supplied	Date Paid	Amount
A.E.C.L. Comm. Products	4 foot long tongs	24/4/78	$ 36.00
Canadian Tire Corp.	Transistor Battery	15/5/78	15.00
Datamex	Personal Digital Dosimeters - Model Prime-V	3/5/78 15/5/78	10,300.00
Datamex	Eberline Beta Gamma Geiger Counter Eberline Beta Gamma Portable Ion Chamber Survey Meter	26/4/78	11,594.00
Ludlum Measurements	Micro-R-Meters	15/5/78	7,088.00
Datamex	Eberline Portable Gamma Dose Rate Meter Eberline Portable Scaler	3/5/78	9,368.00
Datamex	Eberline Portable Beta Gamma Geiger Counters Eberline Beta Window Pancake Probes with cables	3/5/78	2,790.00
Datamex	Vacuum Cleaner with filters	3/5/78	2,030.00
A.E.C.L. Comm. Products	Steel drums (16 gallon)	25/4/78	1,200.00
Radionics Ltd.	Victoreen Personal Dosimeters	24/4/78	4,700.00
Bond Brass Ltd.	Fabrication of 20 Shipping Containers	25/4/78	10,487.02
Superior Electronics	Berthold end window counter tube with cable and adapter jack	25/4/78	5,402.88
A.E.C.L. Comm. Products	Special 5 gallon pails, steel cables with snaps, caulking and 1 gallon pails	25/4/78	239.50
A.E.C.L. Comm. Products	Special 5 gallon pails, lead bricks, lead sheets	25/4/78	546.70
Provincial Cancer Hospitals Board	Construction of 3 containers for Operation Morning Light	25/4/78	649.82
	SUB-TOTAL		$ 66,446.92

ANNEX XIV

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[redacted]

COSMOS 954 - Expenses from April 21 - present

MATERIALS AND SUPPLIES

Name of Supplier	Product or Service Supplied	Date Paid	Amount
A.E.C.L. (Whiteshell Nuclear Labs)	Storage facilities for samples and debris from Cosmos 954	25/4/78	$3,635.94
W.K. Gummer	Telephone call to P. Kennedy in Cape Dorset	03/5/78	3.73
Border Brokers	Shipment of equipment	26/4/78	1,553.41

SUB TOTAL: $5,193.08

TOTAL: $79,664.82

(Includes $1548.11
Travel from Annex I)

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ANNEX XVI

Salary Expenditures 24 Jan. to 20 April, 1978

Name	Days Worked A*	Days Worked B	Salaries Regular Days**	Salaries Total
Beaudry	10	18.2	562.00	1584.84
Blackburn	9	11.4	1260.72	2857.63
Boyd	9	11.9	1190.16	2763.81
Brown	11	4.5	1054.02	1485.21
Cahill	21	35	1609.86	4292.96
Cameron	42.8	11.6	4183.27	5317.05
Campbell	36.6	26.7	3693.67	6388.23
Charlebois	34.5	0	1860.24	1860.24
Chatterjee	18	33.3	1776.60	5063.31
Courneya, O.	9	22.4	843.40	2942.80
Courneya, W.	19	38.9	1948.07	5936.48
Davediuk	10	6.7	1181.80	1973.60
Eaton	22	16	2462.24	4252.96
Elagupillai	33	35.5	3255.78	8731.41
Elks	33.9		3118.46	3118.46
Goyette	26	35.8	1913.34	4547.86
Gummer	39.8	0	5405.63	5405.63
Henry	10	0	1069.40	1069.40
Horvath	13	22.7	924.30	2538.27
James	6	15.8	625.56	2272.86
Jennekens	11	9.6	1763.08	3301.76
Kealy	22.1	4.7	1490.86	1807.92
Kennedy	6	3.5	524.34	830.20
Knight	18	9.9	2337.84	3623.65
Marleau	21	23	1674.33	3508.12
McLellan	26	14.9	2591.16	4076.09
Meloche	2.3	0	146.35	146.35
Molloy	17	22.1	629.00	1446.00
Prince	3	0	557.70	557.70
Ricard	15	22.6	1465.20	3672.76
Robertson	18	25.8	1780.02	4331.38
Shultz	23	32.5	2503.78	6041.73
Smythe	6	0	837.00	837.00
Spence	8	0	803.36	803.36
Tallim	9	0	464.04	464.04
Utting	20	25.4	1839.80	4176.34
White	11	6	1280.95	1979.65
			62,626.63	116,007.06

*A - regular working days
B - overtime credits in days

** Salary for regular working days. The total includes equivalent compensation for overtime credits.

WKO

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ANNEX XVII

Salary Expenditures 21 April to 23 May, 1978

Name	Days Worked	Salaries
Cameron	4.5	439.83
Campbell	10.3	1039.48
Charlebois	4.5	242.64
Courneya, W.	2.0	205.06
Davediuk	3.0	354.54
Eaton	14.0	1566.88
Elks	7.0	643.93
Elagupillai	2.0	197.32
Gummer	9.7	1317.45
Kealey	5.0	337.30
Knight	8.0	1039.04
Prince	1.0	185.90
Ricard	14.8	1445.66
Wawrychuk	2.0	214.00
	87.8	9229.03

WKG

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Schedule B to affidavit to W.K. Gummer
sworned on August 15, 1978.

sentinel

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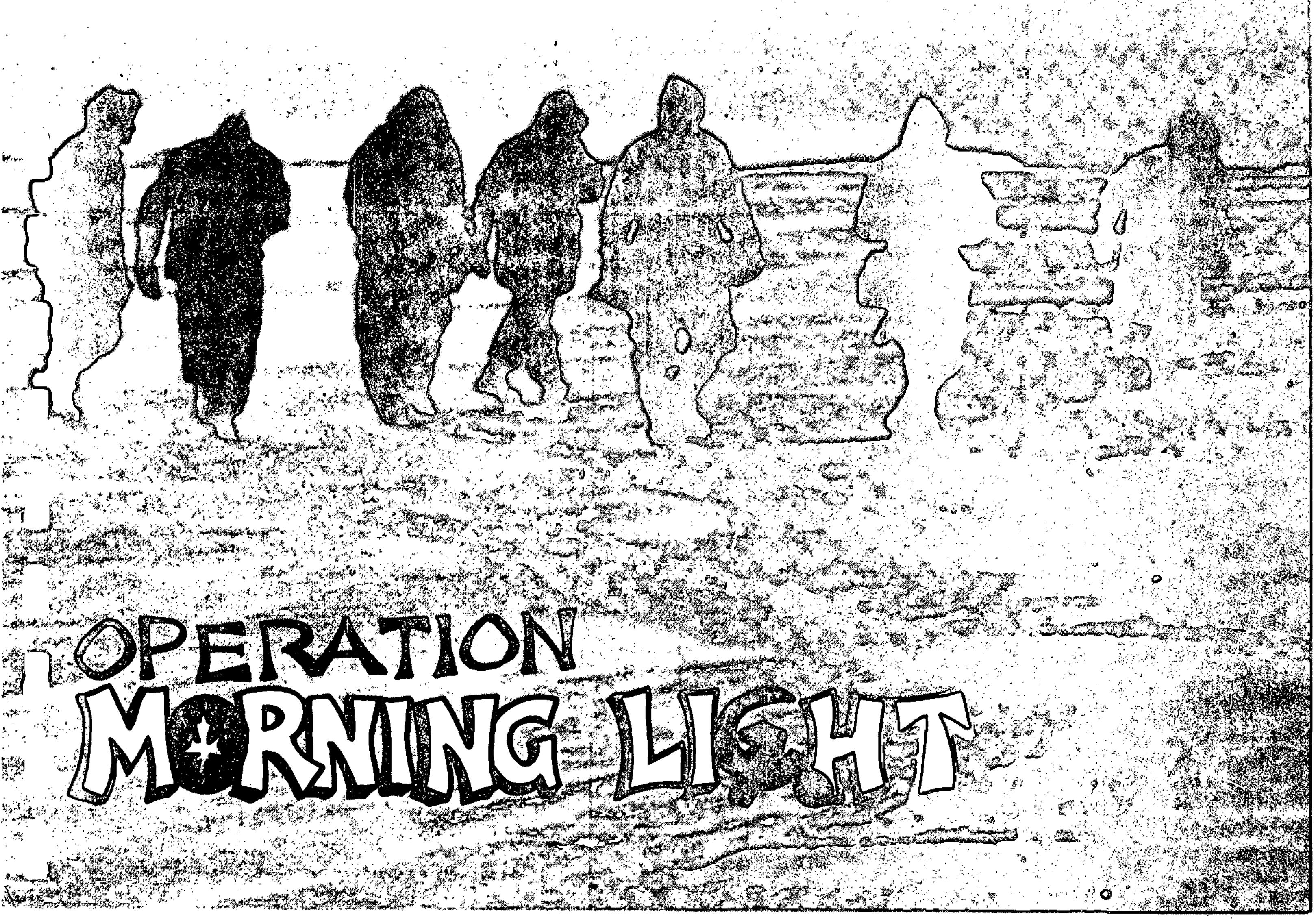

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1978/2
magazine of the Canadian Forces

Volume 14, Number 2
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***Sentinel* Managing Editor Maj. Bill Aikman observes readings on a Hercules-mounted gamma ray spectrometer during a search mission over Warden's Grove. (Dave Jackson photo)**

OPERATION MORNING LIGHT

When Cosmos 954 plunged to earth in the Northwest Territories in late January, the eyes of the world focused on Canada's North and the Canadian Forces.

Within hours, CFB Edmonton was transformed into a huge search centre, crammed with scientists and their exotic equipment. During the next few weeks, aircraft roared off at all hours on their Arctic search missions.

In the months following those frigid January days, Canadian Forces personnel, scientists, and technicians from both Canada and the United States worked together on an operation for which there were no precedents.

Sentinel spent 17 days on Operation Morning Light, following the search team from Edmonton to Yellowknife and Baker Lake, and finally to Camp Garland near Warden's Grove. We found it a rewarding experience to observe Canadian-American professionalism and cooperation working under most demanding conditions.

Our challenge then was to capture the essence of this complex operation in a magazine article. Inevitably there are a large number of people whose efforts deserve a place in the story, but who through lack of space simply could not be included.

Many of the photographs in the magazine are credited to "E.G.&G. photo team." These were taken by photographers from the American Nuclear Emergency Search Team. For their excellent coverage of many key incidents in the search and their generosity in providing us with the photos, we extend our sincere appreciation.

We hope that this *Sentinel* article will give our readers an insight into the biggest CF operation since the 1976 Olympics.

W.R.A.

Cover. Bundled up to protect themselves against the Arctic cold (with wind chill factors below − 100°C), scientists and CF Nuclear Accident Support Team members trudge across the ice of Great Slave Lake, looking for debris from satellite Cosmos 954. (EG&G photo 1503-26)

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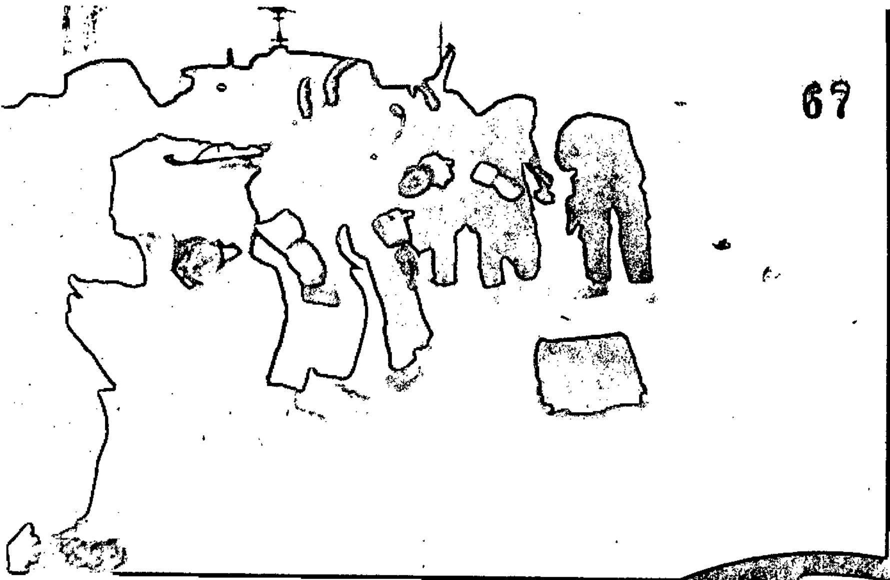
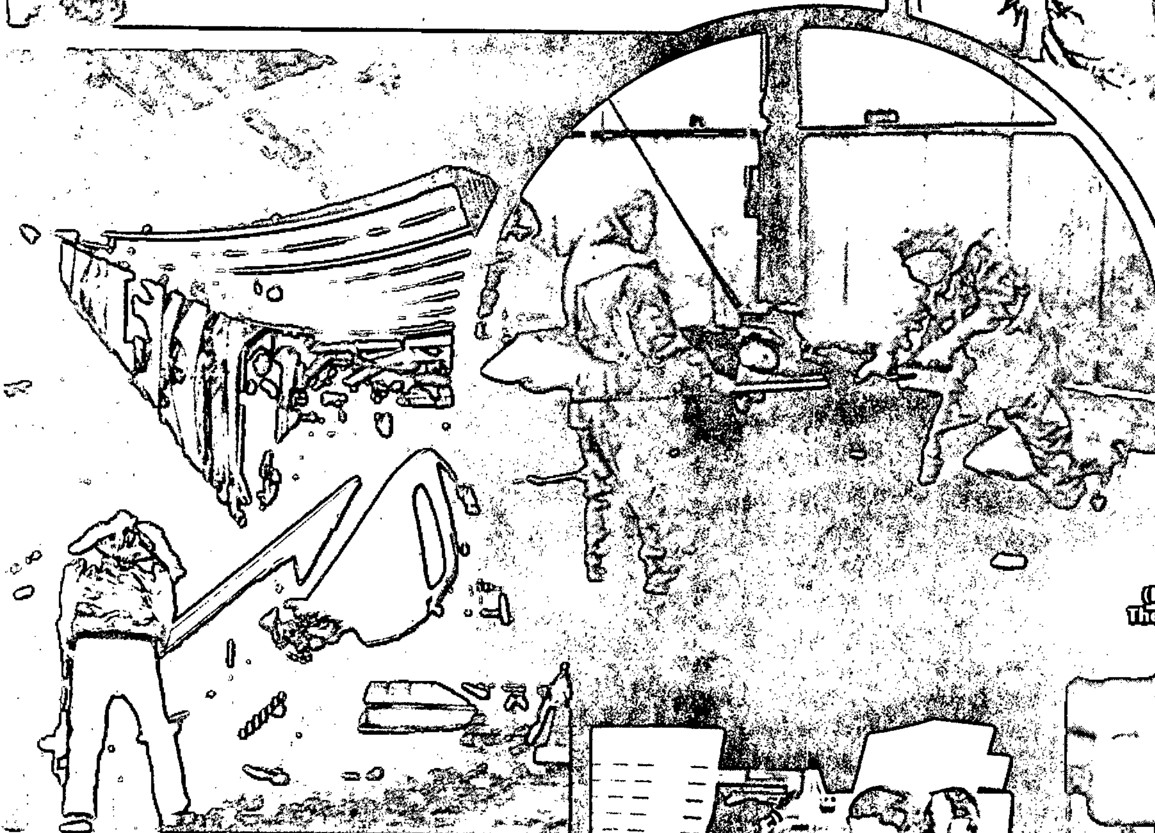
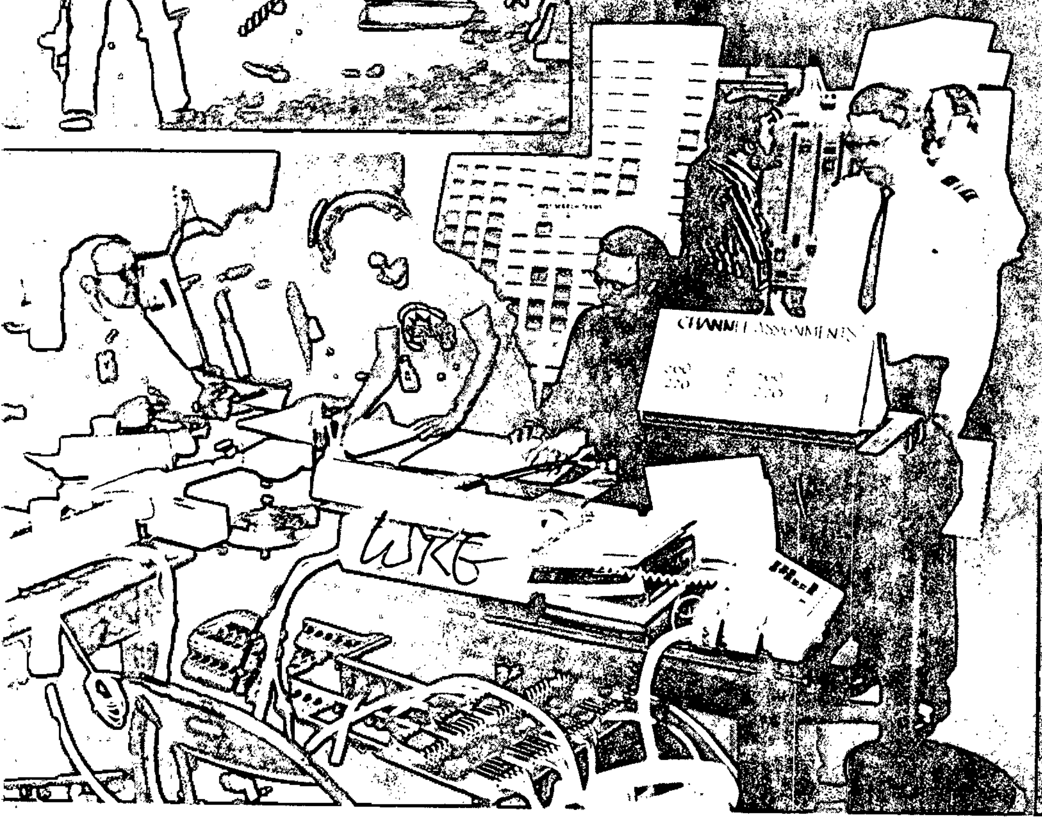




Clockwise from above. A scientist checks snow around a hit site for possible further radiation sources (ISC 78-1073). *Hercules* crew member straps down cask containing satellite debris. (IS 78-1094) Part of the operations centre at CFB Edmonton. (EG&G photo 1561-9). American helicopter containing radiation detection equipment is pushed aboard CF *Hercules* in preparation for first search mission. (EG&G photo). Discovery of satellite remains on Great Slave Lake. (IEC 78-108). Centre. NAST members at Yellowknife handle contaminated material. (IEC 78-252). Right. Debris found on Thelon River. (EG&G photo 1495-3).



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OPERATION MORNING LIGHT

by Major Bill Aikman

At 4:40 a.m. on January 24, at NORAD's Space Defence Centre deep inside Cheyenne Mountain, Colorado, Captain David Tholen, Chief Orbital Analyst receives a message from a telescopic camera station at Maui, Hawaii. The trackers there report that a Russian satellite on a trajectory towards Canada's Queen Charlotte Islands is glowing with [illegible] and is beginning a fiery re-en[illegible] to the earth's atmosphere.

C[illegible] [illegible] reaches for his emergen[illegible] [illegible] notify his NORAD su-[illegible]

[illegible] later, a pat-on [illegible]

[illegible] RCMP constables along [illegible] [illegible] N.W.T. skids to a ha[illegible] [illegible] state [illegible] as brigh[illegible] incandes[illegible] [illegible] in a [illegible] the [illegible]

[illegible] ozens of [illegible] pieces break off and tumble over [illegible] on their way to the ground. [illegible] immedia[illegible] [illegible] quarter[illegible]

[illegible] 54, nuclear-powered Rus[illegible] satellite has disintegrated and [illegible] Canada's Northwest [illegible]

[illegible] of the [illegible] time [illegible] surveillance satellite was not unexpect-ed. Launched on September 18, 1977, the Russian satellite began behaving ab-normally within weeks. Soon NORAD's computers were predicting that the satellite would fall in April, 1978.

However, in early January, the computer predictions were revised to January 23, plus or minus 48 hours. During this critical period, Cosmos 954 would orbit the earth several times, and would overfly Australia, New Zealand and North America. On January 19, the American government notified all nations potentially involved of the developing danger and offered American assistance.

The next day, senior Canadian government and military personnel discussed the situation. After the meetings, National Defence Headquarters sent warning orders to all regional commanders and Nuclear Accident Support Teams (NAST) in bases across Canada.

The conferences continued for several days. Still no one could be certain of where the satellite would re-enter the earth's atmosphere.

DND was assigned the lead role in the potential search for the radioactive debris, and the Atomic Energy Control Board (AECB) was assigned responsibility for the recovery of any debris.

Then came the fiery re-entry of Cosmos 954 somewhere over the Northwest Territories.

Fourteen minutes later, President Carter of the United States telephoned Prime Minister Trudeau to advise him of the situation, and to repeat the offer of American assistance.

The Canadian government was now faced with several urgent questions. Had the intensely radioactive core disintegrated while re-entering the earth's atmosphere? Or had it crashed, with its potentially lethal fragments radiating from the depths of the all-encompassing snow? Or had both occurred?

OPERATIONS BEGIN

President Carter's offer was accepted. Soon the wires between the two capitals were humming as commanders made their initial contacts and plans.

Operation Morning Light, the search for the radioactive elements of Cosmos 954, had begun.

Operational responsibility was assigned to the Commander of Air Command, Lieutenant-General William Carr. He in turn assigned on-scene command to the Base Commander of CFB Edmonton, Colonel David Garland.

The first search efforts were directed towards identifying major radiation sources, particularly in inhabited areas. NORAD's calculations indicated that the satellite, after a fifteen minute re-entry through the earth's atmosphere, had crashed somewhere between Yellowknife on Great Slave Lake and Baker Lake, [illegible] km to the northeast. This was [illegible] [illegible]unate, for the land between [illegible] points consists of the Barrenlands, for the most part a treeless, uninhabited area.

South of the computed track, on Great Slave Lake lay the communities of Fort Reliance, Snowdrift, Hay River and Pine Point.

Col. Garland immediately dispatched 25 members of the CFB Edmonton NAST team to Yellowknife, 1,000 [illegible] farther north by air. They were to check

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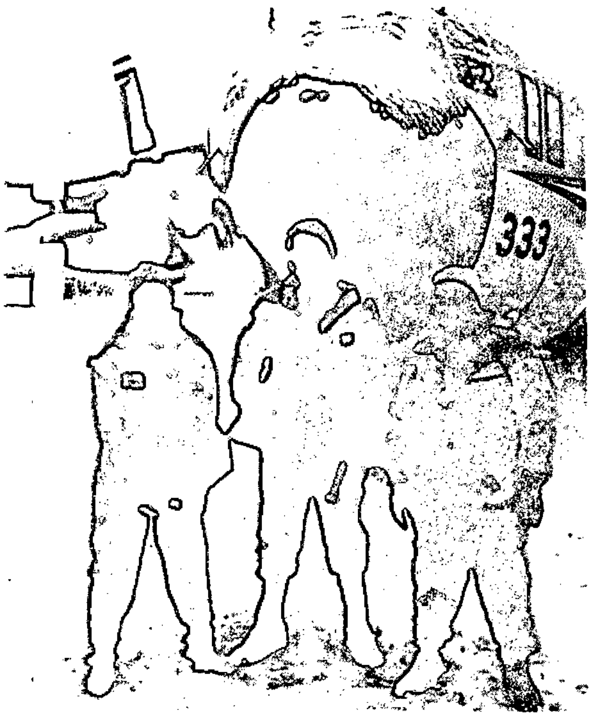
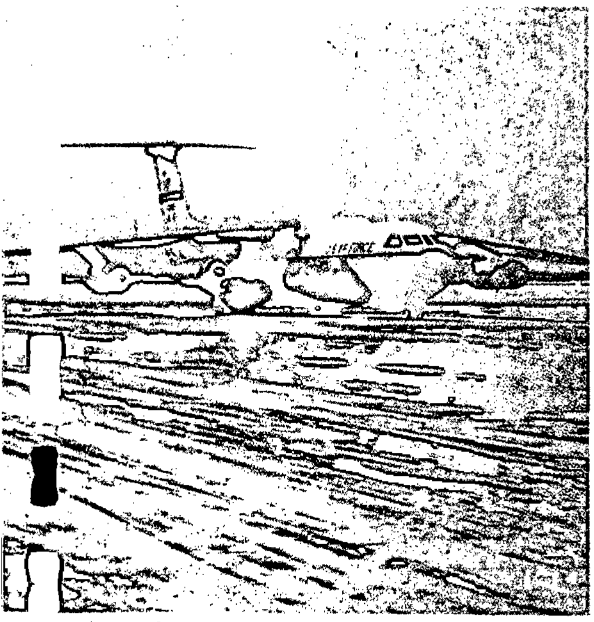


Above. NAST members in their full kit. Below. The first American C-141 lands at CFB Edmonton.



The American commander, Brig-Gen (ret'd) Mahlon Gates and the Canadian commander, Col. David Garland, discuss search operations. (EG&G photo 1561-41)

the city (population 10,000) and the other smaller communities for radiation.

Under the command of Capt John Lyne, the NAST team departed shortly after noon for Yellowknife, and arrived in time to carry out a detailed survey of the town that evening. The normally easy-going citizens of Yellowknife were startled by the sight of yellow-garbed troops walking the streets, reading radiation meters and taking air samples. Tension dropped when negative results were announced.

By noon that day, American search activity had begun. One U-2 and one KC-135 jet aircraft with special radiation monitoring equipment aboard were winging their way north to check the upper atmosphere along the satellite's path, to ascertain whether or not a radioactive cloud had been created by the disintegration of the nuclear reactor and its Uranium 235 core. The results were negative.

The first search efforts had provided no hint as to what had happened to Cosmos 954.

SEARCH FORCE ORGANIZES

Meanwhile, back at Edmonton, the entire base prepared itself for the onslaught of technicians and scientists, both Canadian and American, and for extended search operations. The Morning Light Operations Centre was set up, and supply technicians, transport drivers, cooks and telephone operators readied themselves and their equipment for days or weeks of round the clock operations. At the same time aircrew, groundcrew and maintenance personnel for 435 Squadron's *Hercules*, 408 Sqn's *Twin Hueys* and *Kiowas*, 440 Sqn's *Twin Otters* and 450 Sqn's *Chinooks* went on standby for search operations.

Far to the south the Americans were mobilizing their search effort. Several years ago, the U.S. Department of Energy (DOE) organized Nuclear Emergency Search Teams (NEST) to search for and locate lost or stolen radioactive materials. The NEST expertise proved to be tailor-made for the Cosmos 954 search.

The NEST system is based at DOE's Las Vegas, Nevada operations office (the same office that runs the Nevada nuclear test site). Under the direction of Brig.-Gen (ret'd) Mahlon Gates, the NEST organization had been preparing itself for the plunge of Cosmos 954 for several weeks. Team members had been detailed, equipment had been selected and loaded on pallets, and by January 22 five fully-loaded C-141 *Starlifters* were sitting on the ramps at McCarren International Airport near Las Vegas, at Andrews A.F.B., Washington, D.C. and at Travis A.F.B., Cal., all ready to go.

Since there was no reliable information on where the satellite would land, many of the scientists had two bags packed; one with summer clothing, the other with winter clothing.

By mid-morning of January 24, arrangements between Canada and the U.S. were falling into place. It was agreed that the NEST organization would operate out of Edmonton under the direction of Col Garland. Two C-141's lifted off from McCarren and Andrews just after noon with over 70 Americans aboard, and by suppertime were touching down at Edmonton's Namao Airport.

At almost the same time, Dr. Bob Grasty of the Geological Survey of Canada arrived at Edmonton from Ottawa. Dr. Grasty, a specialist in aerial survey for radioactive materials, was the first of approximately 30 Canadian scientists and technicians from the Atomic Energy Control Board (AECB); Energy, Mines and Resources (EMR) and Environment Canada who would work with the CF and the Americans in the search and recovery organization.

That night the Americans moved their equipment into a hangar at Namao, picked up CF winter clothing, and met with the Canadians to work out the plans of operation.

One of the first points resolved was the search area. Using computer reentry predictions, the scientists plotted a 50 km wide zone starting at a point on Great Slave Lake 80 km southeast of Yellowknife and running 800 km northeast towards Baker Lake. The potential "hit" area was huge, approximately 40,000 sq km. For planning purposes it was divided into eight equal sectors.

HERCULES SEARCH

Search procedures were also clarified. First, there would be a general search of the area, using the C-130 *Hercules* of CFB Edmonton's 435 Transport Squadron. Each *Hercules* would carry a gamma ray spectrometer, a device designed to determine the amount of radiation emitted from a ground source. Each aircraft would fly a grid pattern 1,000 ft over the suspected satellite crash area, with the lines of the grid one nautical mile apart. If the equipment detected a hit (the search teams' term for a suspicious reading on the spectrometer), the location would be noted for detailed checking later by helicopter-borne recovery teams.

One Canadian gamma ray spectrometer (designed for uranium exploration

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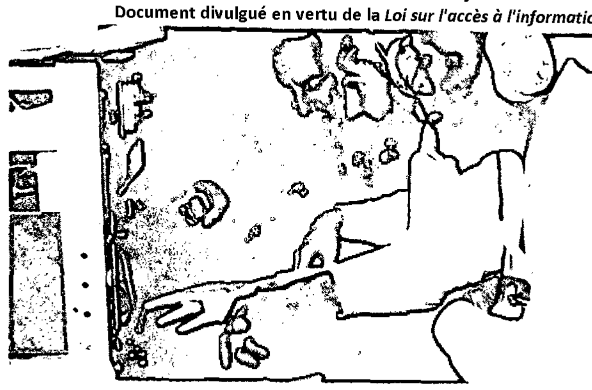
and geological mapping), was shipped from Ottawa. In the meantime, the American NEST organization arrived with three. Two spectrometers were already mounted in two *Hughes 500* helicopters, which had been transported to Edmonton by the *Starlifters*.

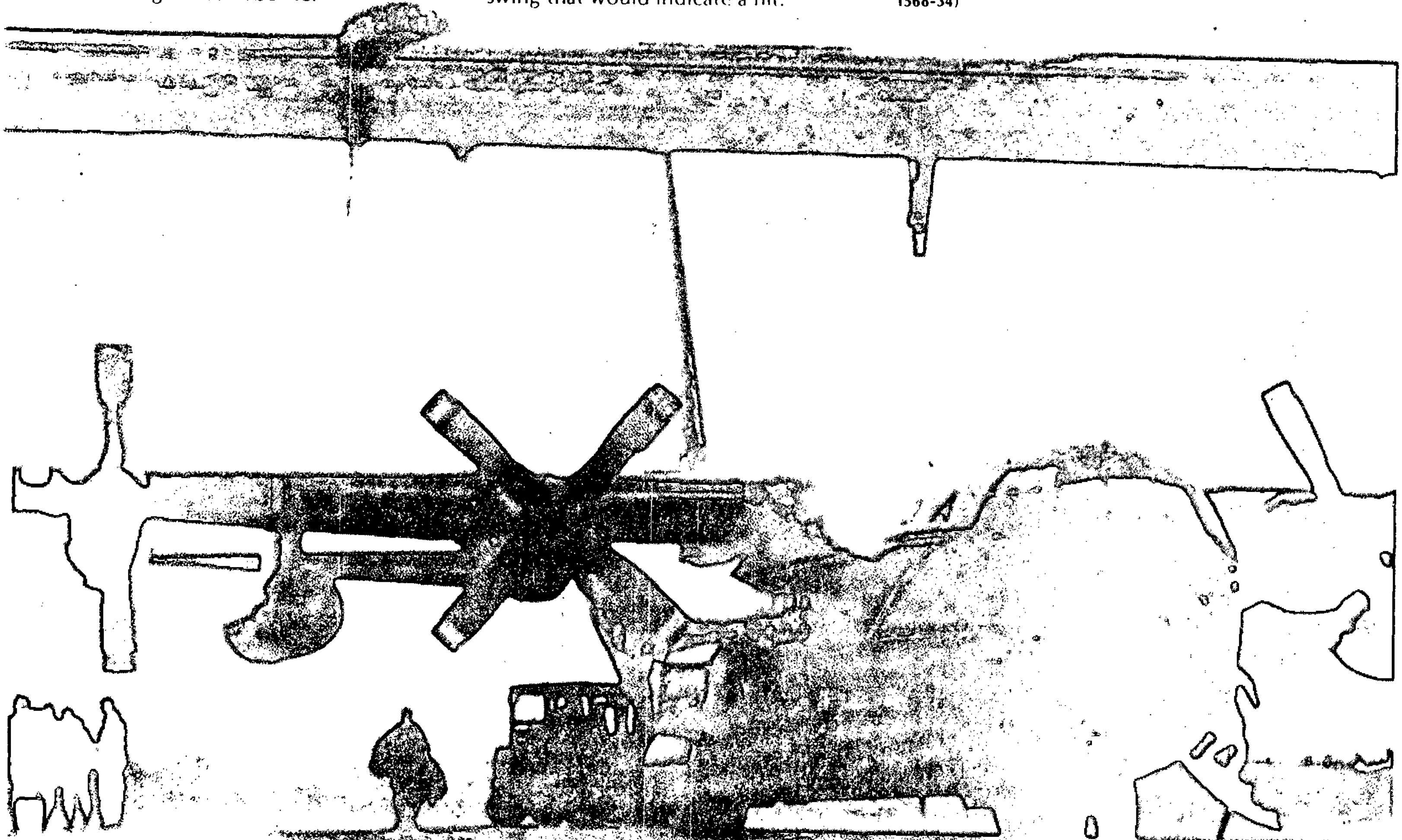
However, the limited range of the helicopters precluded their use in the vast North. Rather than waste time dismantling and transferring the equipment, one of the helicopters was pushed into the back of a CF *Hercules*, and at 1:30 a.m. on January 25, the first search flight was airborne.

clear reference points. North of the treeline the pilots looked out on a white featureless land where only instruments could assist in maintaining accurate lines. In an area with few navigational aids and a reputation for compass unreliability, the aircrew and scientists had cause to worry about their ability to pinpoint a hit.

Meanwhile, back in the cargo compartment, the scientists took turns watching several needles as they slowly swayed up and down across a piece of graph paper, waiting for the telltale swing that would indicate a hit.



Above. Scientists spent hours in the back of *Hercules* aircraft, watching for the swing of a graph needle which will indicate a hit. (EG&G photo 1447-5). Below. The workhorse of Operation Morning Light; a CF *Hercules*. (EG&G photo 1568-34)



Three *Hercules* carried out five search missions that day. Soon the rhythm of the search developed. An aircraft would take off for a 12 to 14 hour mission. Upon return it would refuel and take off again with a new crew and team of technicians. Fourteen hours later the cycle would begin again with another crew.

In the air, the work was tedious. The aircrew took meticulous care to keep on course as the aircraft lumbered up and down imaginary lines one mile apart across the tundra.

Navigation was a major problem. South of the treeline (which cuts across the projected satellite track just northeast of Great Slave Lake) there were

Late Wednesday night they had their first success. A *Hercules* with an American team aboard reported a hit in sector five, approximately 300 km east-northeast of Great Slave Lake. But, when the tapes from the gamma ray spectrometer were run through a computer in Edmonton, the proportions of uranium, thorium and potassium were not what could be expected from a Uranium 235 core. The scientists faced one of the classic problems of this search. The rocks of the North are full of uranium, thorium and potassium in varying concentrations. Was this hit an outcropping of natural uranium, or was it a piece of the reactor core, so dense that it had buried itself deep into the tundra? Or was the search equipment simply miscalibrated? Exhaustive discussions on this matter continued for the next few days.

BAKER LAKE

It soon became clear that if downrange hits were to be checked out, a forward search detachment had to be set up nearer that end of the search area. On January 26, the centre of the search shifted to the east when Lieutenant-Colonel Donald Davidson flew into Baker Lake with a mixed American-Canadian scientific team, a photographer, a rescue specialist and communications personnel.

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The two men who discovered satellite debris on the Thelon River, Mike [illegible] and [illegible], point out the site on a map. (EG&G photo 1581-34). Below: The first search team at the Thelon River hit site. (EG&G photo 1495-13).

The same day a 450 Squadron *Chinook* helicopter arrived from Yellowknife with three NAST team members. The *Chinook* had flown 3,000 km directly from an army exercise in the Chilcotin area of British Columbia.

That night, the detachment carried a radiation check of Baker Lake, a community of approximately 1,000 Inuit. Operations were set up in the Iglu Hotel, a large quonset hut. During the next two days, in -40°C temperatures, they carried out the first helicopter searches at the far end of the search zone, with negative results. (See Baker Lake story on p. 22).

HITS CONFIRMED

At the operations centre in Edmonton, resources available for the search continued to increase. The Canadian gamma ray spectrometer arrived on the morning of the 26th, and was quickly installed in a fourth *Hercules*. The Canadian scientists were keen to watch its performance, as the spectrometer had been designed and built only last year by Quentin Bristow of the Geological Survey of Canada.

A U.S.-DOE *Convair* turboprop aircraft arrived the same day to begin flying infrared search and photographic runs over the satellite track. On January 29, two *Argus* maritime patrol aircraft arrived from CFB Summerside to assist in the search. The *Convair's* infra-red searches were to prove fruitless, but its photographic runs plus those of the two *Argus* provided invaluable aerial photos of hit sites and the entire search area. In the afternoon a team of AECB scientists arrived in Edmonton to round out the initial Canadian-American search team.

At this point, the tally of CF aircraft now involved in Operation Morning Light included four *Hercules*, four *Twin Otters*, three *Twin Hueys* and two *Chinooks*.

On the night of the 26th, a *Hercules* carrying the Canadian spectrometer loaded up with its crew and technical team plus a dozen journalists, eager to observe the search activity. The aircraft lifted off and headed north to search a section near the eastern end of Great Slave Lake. Soon everyone aboard was experiencing the monotonous search routine as the aircraft began the steady, laborious job of tracking along grid lines.

On the 17th and final pass, reporter Sid Handleman from the Toronto Star leaned over the shoulder of spectrometer operator Bob Grasty and asked why the needle was swaying so much. Grasty replied enthusiastically "I think we've got a hit." As everyone crowded around, the scientists and aircrew pinpointed the radiation source on near Great Slave Lake, just off the mouth of the Hoarfrost River, 27 km north of Fort Reliance.

Computer analysis confirmed the hit. Two days later a second aircraft not only reconfirmed it, but also found several more hits in the same area. Operation Morning Light had its first unqualified success.

THELON RIVER

However, these discoveries were all but forgotten with the news that two young men had found pieces of metal at a site farther east. On January 28, the Yellowknife meteorological station received a radio message from six men camping for the winter at Warden's Grove on the Thelon River, halfway between Yellowknife and Baker Lake. They reported that pieces of metal were protruding from the frozen surface of the river, 12 km from their camp.

Two of the men, John Mordhorst and Mike Mobley, had left the campsite on January 25 to travel by dogsled north along the Thelon River to learn more about the barrenlands. That morning they saw nothing as they passed the crash site along the far side of the river. Returning on January 28, the men turned off their trail to discover more about the area to the west of the Thelon. As they mushed around the river bend, they saw several pieces of metal extending out of a re-frozen crater. Mike Mobley walked up to the crater and touched the strange metallic structure. Not knowing exactly what he was dealing with, he backed off. The two men cut their trip short, and returned directly to the camp at Warden's Grove.

The four other campers had already learned of the satellite's crash on their radio, after querying Yellowknife about the frequent overflights of search aircraft. The group immediately reported the discovery.

An incredible chain of unlikely events had occurred. A satellite with little likelihood of coming down on land or of surviving re-entry through the earth's atmosphere had done both. It had then broken up and spread across hundreds of kilometres of almost totally uninhabited snow-covered land. And two men, in the midst of that vast expanse, had stumbled upon several pieces within four days of the fiery crash.

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The immediate effect of this report and the Hoarfrost River area discoveries was to bring the centre of the search back to Yellowknife. For the past few days, the staff at Northern Region Headquarters had monitored the search activity, but apart from a NAST check of Fort Reliance which revealed negative radiation readings, there had been little activity.

All this changed within hours. Under the command of LCol Alex Bialosh, a combined Canadian-American scientific team flew north, arriving in Yellowknife late in the night of January 28. By the next morning the new forward search detachment was functioning out of the NRHQ operations room.

The main objective that morning was to get into Warden's Grove and get the six adventurers out for a medical examination. The Thelon hit site was dead on the predicted satellite track, and the men's description of the crater gave the impression that something large and dense (perhaps the nuclear core) had penetrated the ice. If Mobley and Mordhorst had been exposed to enough radiation, they and their friends could be in grave danger.

A *Chinook* helicopter at Baker Lake lifted off for Warden's Grove as soon as the technicians could warm it up enough to start (a major problem at 40 below), and a *Twin Otter* flew east from Yellowknife carrying NAST members and Dr. Savino "Beanie" Cavender, M.D., an American nuclear medicine specialist. From Edmonton a *Hercules* took off carrying a gamma ray spectrometer, to check the hit site and to provide navigation assistance if required.

The *Twin Otter* picked up the four men who had not been to the crash site, and returned directly to Yellowknife. Mobley, Mordhorst and Dr. Cavender climbed aboard the *Chinook* for the short trip to the crash site, soon to be known as "Satellite One".

Faced with a radiation source of unknown strength, the search team was extremely wary of landing at the site. The helicopter came down on a small rise 500 metres away (where, a week later, a military camp would rise). LCol Davidson, NAST member Pte Mona Wilson, two American scientists and a photographer then waded through hip-deep snow towards the hit site, carefully monitoring their radiation meters.

The tree line extends north here, following the protection of the river valley. The search team gamely floundered through the snow and scrub brush until they reached the hard-packed wind-swept surface of the river. Then they slowly moved forward. The radiation readings remained relatively low. The protruding metal produced readings of 10 to 100 milliroentgens per hour, not the several hundreds of roentgens per hour that the solid core would produce.

Had a major piece of the satellite crashed through the ice and imbedded itself in the river bed? The scientists could not immediately resolve that question. Time was running out.

The team was experiencing one of the major problems of the search. Satellite One was 400 km from the nearest airport (Baker Lake), and a one way trip took 2½ hours. Coupled with the extremely short Arctic day (approximately seven hours in late January), possible on-site time was a maximum of two hours.

Soon the helicopter pilots were urging the team to pack up and return. There was just enough time to photograph the site, take basic measurements, collect samples for later analysis and leave.

As the *Chinook* flew back to Baker Lake, the team learned that the gamma ray spectrometer in the overflying *Hercules* had discovered several more hits in the area.

The search force did not know it at the time, but fortune had been with them. The Arctic high pressure area which had brought frigid cold but calm weather to the area since the beginning of the search was about to end. By next morning, high winds would obliterate the Satellite One site. The opportunity to take detailed photos of the splash pattern (so valuable later in analyzing what had happened) would have been gone.

That night, Mike Mobley and John Mordhorst were flown from Baker Lake to Edmonton and placed in hospital to be tested for radiation exposure. The doctors soon concluded that they were perfectly healthy, with no more radiation exposure than one would receive from one or two X-rays.

The next day at a news conference they cheerfully related their experience to the world. When asked how he felt, Mike jumped and kicked his heels.

Upon their release from hospital, the two men were hired by the CF to act as guides in the Thelon River area. When that job ended they returned to their small campsite at Warden's Grove.

That night the CF became concerned about the security of the Satellite One crash site. The radiation situation was still not clear, and there were rumours that members of the news media were chartering aircraft to fly into the primitive Warden's Grove airstrip.

The media flight never materialized. Instead, before dawn on January 31, four paratroopers from the Canadian Airborne Centre in Edmonton parachuted into Warden's Grove to set up a guard and take care of the dog team left behind when the men flew out. (See paratroopers' story on page 11).

GREAT SLAVE LAKE SEARCH

As the scientists analyzed the puzzling results of the Satellite One find, and reporters from around the world scrambled to interview the adventurers, operations out of Yellowknife continued. LCol Bialosh flew in with several NAST members and scientists to the Fort Reliance area to pinpoint the initial hits.

At this point in the search, the *Hercules* crews could give only an approximate position of the hits they discovered. *Twin Hueys* carrying radiation monitoring equipment then flew low over each hit site, circling until the hit was confirmed and its general location narrowed down. Then the scientists accompanied by NAST members would disembark from their *Chinooks*, spread out across the ice, and sweep the area. When the meters started to indicate a reading, the team would home in on the signal until they found the source. It was a process which demanded long hours on the wind-swept ice, in the bitter cold of the Arctic winter.

In this manner a 20 R/hr piece was located at hit one. It was a small metal bar, only a few inches long. The site was marked with flags and tape so that

Searcher puzzles over the debris at Satellite One hit site. (EG&G photo 1469-35)

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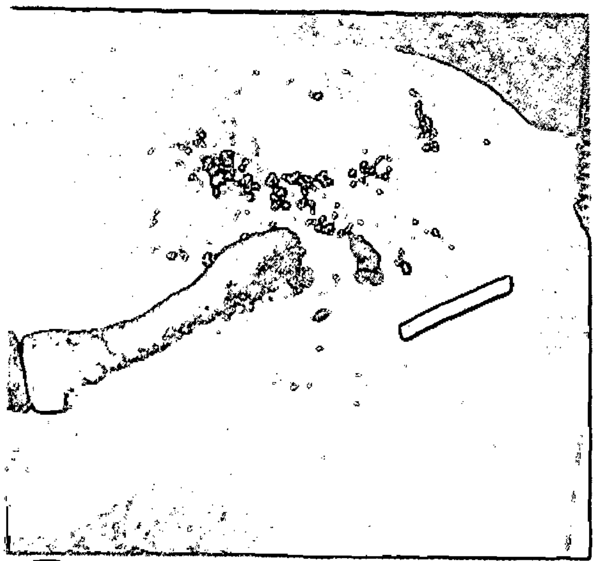
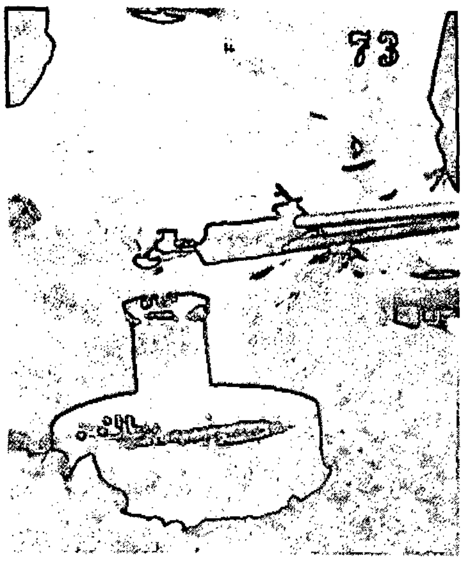
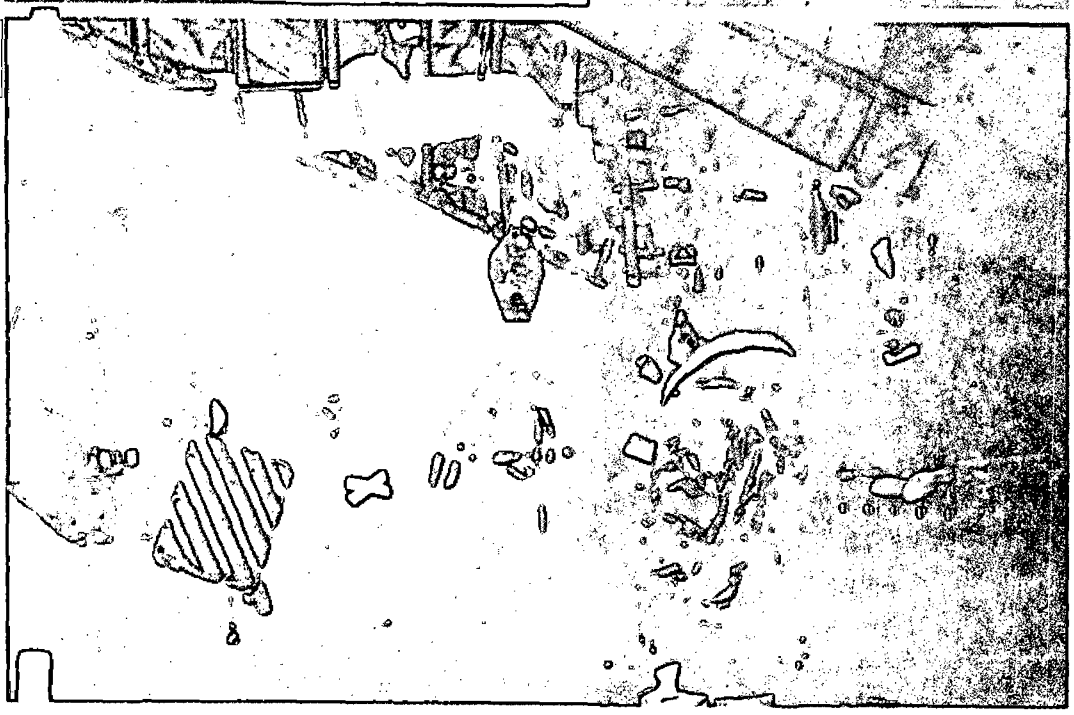




Far left. The pieces of the puzzle start to come together. (EG&G photo 1507-6). Left. Using long tongs, a scientist places small pieces of radioactive debris in a lead container. (EG&G photo 1591-3).



Above. Lead pig used to protect people from 200 R/hr source was so heavy that a recovery vehicle was used to transport it from aircraft to storage area. (EG&G photo 1540-18). Below left. NAST members carefully check the clothing of all recovery team members to ensure it is not contaminated. (EG&G photo 1522-20). Below right. NAST member checks Snowdrift natives for contamination. The results in all cases were negative. (News of the North photo)

recovery crews could return with a lead-lined cask to pick up the piece. Later the radioactive material would be shipped to the Atomic Energy of Canada Ltd's Whiteshell Nuclear Research Establishment (WNRE) at Pinawa, Man.

On Jan 30, the search teams returned to the eastern end of Great Slave Lake. This time they took with them two RCMP constables and two NRHQ military policemen to guard the hit sites. Aware that the radioactive pieces were only a short snowmobile ride from Fort Reliance, they were determined to prevent casual visitors. The weather had changed for the worse, forcing the site guards to pitch their tent out of the wind in the lee of a point of land 200 metres away.

With this job complete, the searchers turned to the task of checking hit two, a short distance away. Out on the open ice, with winds now so high that the wind chill factor was dropping below -100°C, the team set up their search pattern.

As they started to walk towards the suspected hit site their personal radiation dosimeters began emitting a high pitched chirping sound. Soon the air was filled by what sounded like a field of crickets. Suddenly needles on hand-held instruments began to bounce off the low range scales. The team had located a small piece of metal emitting 200 R/hr.

The search team carefully marked the site, and, again faced with limited onsite time, returned to Yellowknife.
There the scientists puzzled over the problem of recovering the 200 R/hr source.

None of the normal AECB lead-lined casks were designed to provide protection against such a powerful source, and a man exposed to only two hours of such radiation would probably die. The only solution was to manufacture an appropriate container. The job was given to technicians at the University of Alberta, while the search teams continued with other search and recovery efforts.

That same day, a NAST element flew to Snowdrift, to check the 90 Indian residents for radiation. As the team disembarked from its aircraft and spread throughout the village, the natives fled indoors. They didn't know what was happening, and they didn't like it. The next day NRHQ commander, BGen Ken

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JUMP INTO NOWHERE

On a quiet Sunday evening at the end of January, Sergeant John Phillips received a phone call from his headquarters at the Canadian Airborne Centre in Edmonton. He was to report immediately, with his winter clothing in hand.

When he arrived at Griesbach Barracks, he met three other men with the same task: Sgts Doug Riddell, Chris Cableguen and Cpl John Wickstrom. Their mission — to parachute into Warden's Grove in the middle of the Arctic barrenlands, and secure the crude airstrip there to prevent unauthorized personnel from inspecting the Cosmos 954 crash site.

It would mean a night drop into an unknown area, 400 km away from the nearest community. It would also be the CF's first operational night drop in many years.

That evening the four men packed and rigged their equipment for airdrop and drew personal weapons, ammunition and rations for five days. They were advised that six men had been hurriedly flown out of Warden's Grove, and that six Husky dogs had been left behind.

By midnight the paratroopers were on their way north in a C-130 *Hercules*. At Yellowknife they received a note from the Warden's Grove residents on an important subject — the care and feeding of the dogs.

The stop in Yellowknife was just long enough to confirm the drop procedures. Then the *Hercules* was off again, roaring through the night towards Warden's Grove. By early morning the plane was circling over the site in total darkness, while the weather below deteriorated. Reports indicated temperatures of −40°C, and winds in excess of 30 knots.

With the assistance of an Edmonton-based rescue specialist, flares were dropped, and under their brilliant light the paratroopers surveyed the scene. The adventurers' campsite consisted of two small cabins, a tent and a small dog kennel, all under the lee of a 100 metre high ridge. The Thelon River is approximately 400 metres away. The airstrip runs between the river and the camp.

Once orientation was complete and a drop zone selected, they dropped lighted drift indicators to ascertain wind strength and direction. On the basis of that information, the aircraft descended to 1,000 feet and a heavily-laden toboggan, followed by the four men, hurtled out into space.

Caught in a swirl of cross winds, only the first man in the stick, Sgt Phillips, landed on the drop zone. The other three, after only a few swings under their chutes, landed on the top of the boulder strewn ridge.

The three less-than-lucky paratroopers bounded among two metre high boulders before their chutes collapsed. Fortunately no one suffered anything worse than bruises.

The next task was to find the toboggan. The wind had caught its parachute, and without anyone to collapse it the toboggan had careened off the ridge, down the slope and across the tundra. Following its tracks across the snow, the men were relieved to find both parachute and toboggan caught in a stand of stunted trees on the river bank. If the equipment hadn't been stopped by the bushes, the wind would have dragged it across the treeless tundra for kilometres.

Re-united at the campsite, the paratroopers radioed the still-circling *Hercules* and advised the aircrew that all was well. Only then did the aircraft leave.

On the ground, the four men checked the campsite and found the sled dogs sound asleep. The activity hadn't bothered them a bit.

A day later, a *Chinook* from Baker Lake dropped M/Cpl Pat Callaghan, a CF rescue specialist, and RCMP Constable Bob Grimstead at the satellite crash site 12 km from Warden's Grove. From that point on the paratroopers' prime task became secondary.

The paratroopers remained at Warden's Grove for a week, receiving occasional visits from supply aircraft and from the RCMP, who flew in two constables to assist in protecting the crash site. The only other visitors were the animals that abound in the Thelon River area, a federal game preserve.

One Arctic fox, nicknamed Grover, was so friendly that he would go right up to the soldiers. He lost some of his popularity the night he discovered that toboggan lines sweaty from human hands contain salt. He ate three metres worth before he was stopped.

On February 7, the first of the original Warden's Grove residents returned, and the paratroopers flew out. After the excitement of the first night, the paratroopers found their quiet week just fine.

Above left. During their stay at Warden's Grove, paratroopers worked out with the adventurers' dog team (IEC 78-448). Below. The four paratroopers in front of the Warden's Grove cabin. Left to right are Sgts Doug Riddell, Chris Cableguen, John Phillips and Cpl John Wickstrom. (IEC 78-436)

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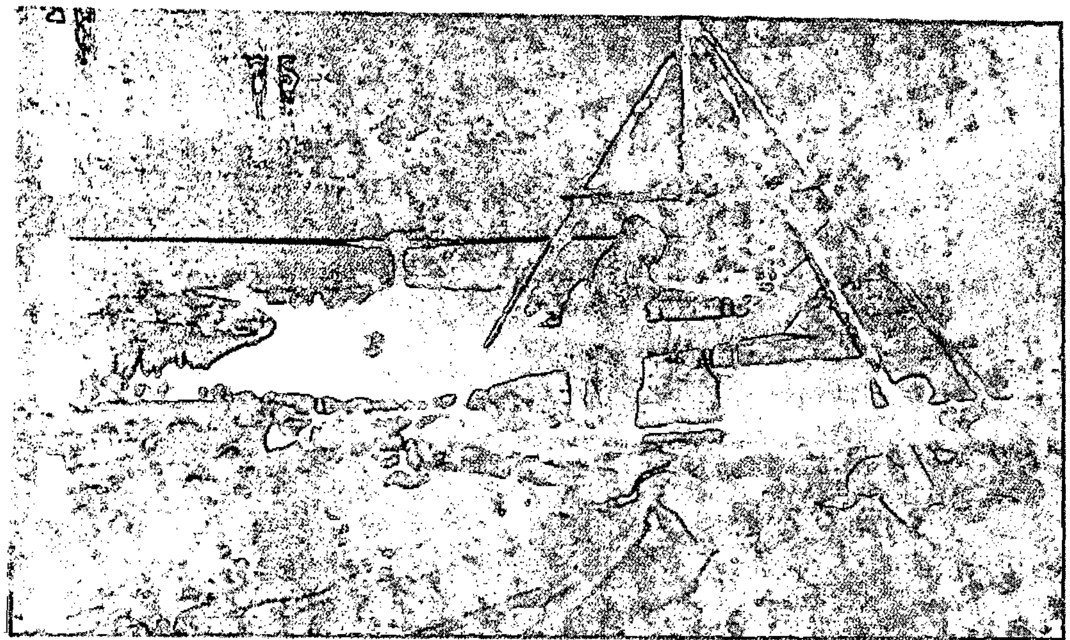
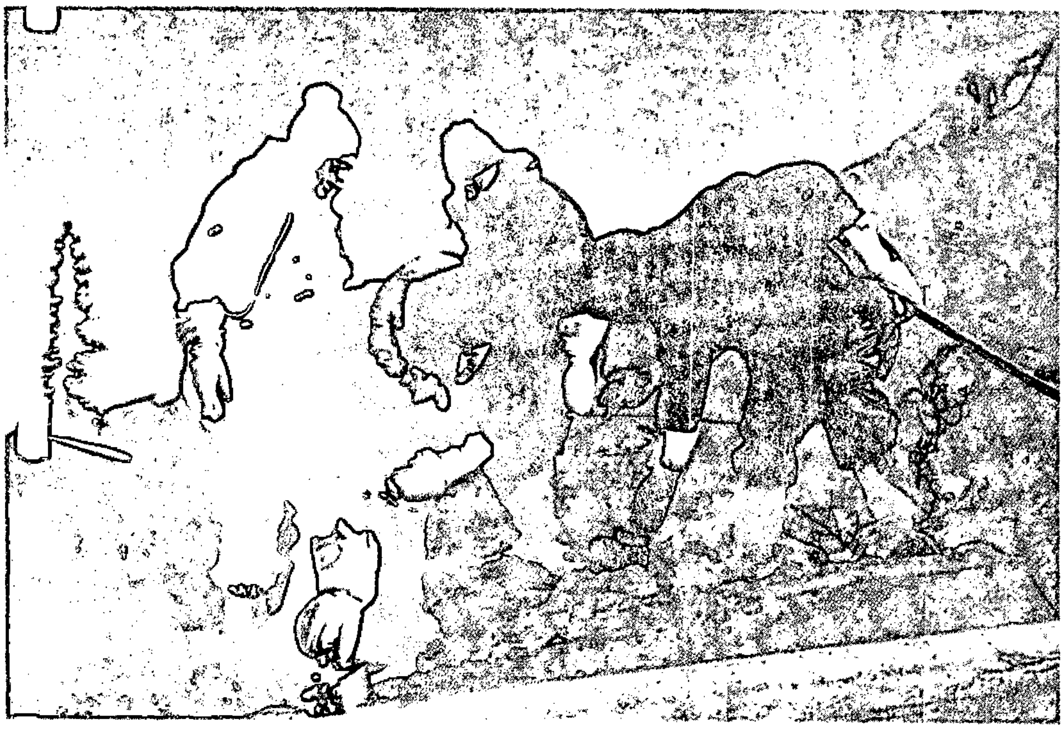
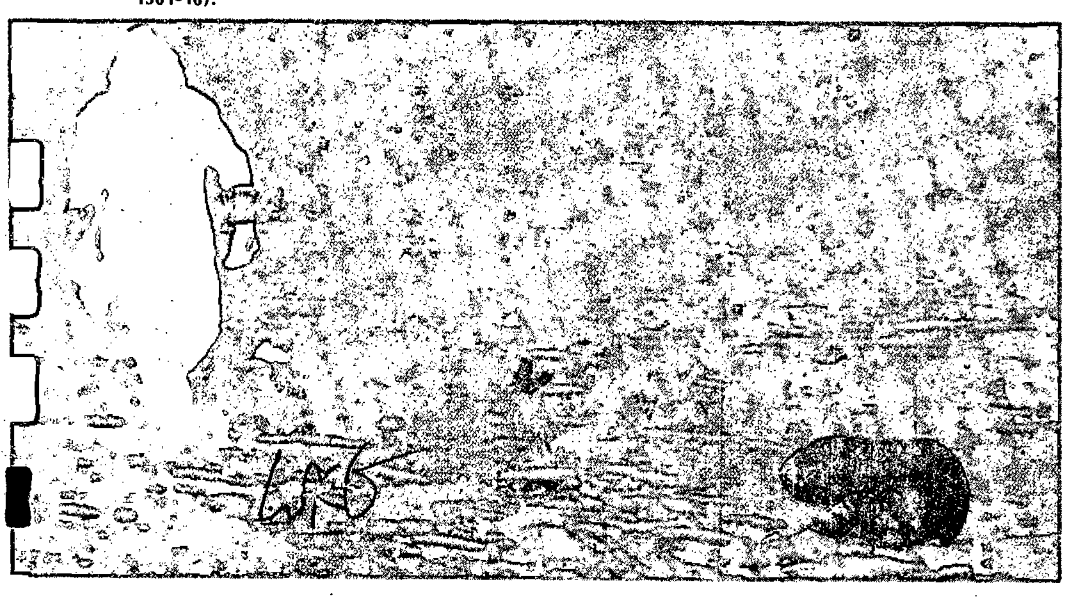


Above. A *Twin Huey* waits while a scientist prepares to change the batteries on a microwave ranging system beacon. In the extreme cold, the batteries had to be changed every 48 hours. (EG&G photo 1566-19).



Above. A CF/scientific search team uses radiation meters to locate a small piece of radioactive debris. (EG&G photo 1571-24). Below. A scientist approaches debris found on Great Slave Lake. (EG&G photo 1501-16).



Thorneycroft flew to the village to explain the situation, and advise them that no radioactive sources had been found in Snowdrift.

On January 31, the Yellowknife-based recovery teams flew by helicopter over the ice of Great Slave Lake to recover the 20 R/hr source at hit one. As they flew eastward, they received a radio message from a nearby CF *Twin Otter*. Something had been spotted on the windswept ice of the lake.

The helicopters landed. This time the dosimeters did not break into their peculiar chirping. Instead the searchers came across a large stovepipe-shaped tube, charred from re-entry. Lying about in snow were a large number of smaller pieces. All were non-radioactive, and were quickly bundled up for transport to Yellowknife. The markings on these fragments furnished conclusive proof that Operation Morning Light had located parts of a Russian satellite.

The team then continued on its mission to recover the 20 R/hr source. Using long tongs, an AECB scientist carefully picked up a small metal rod and dropped it into a lead-lined cask.

But something in the area still emitted radiation. The 20 R/hr source had masked the presence of other radioactive pieces. After a brief search the team found another fragment, and it too was deposited in the cask. Multiple sources were to become a common discovery over the next few weeks.

Properly sealed, the lead-lined cask was flown back to Yellowknife, and later to Pinawa.

Recovery teams and aircrew were checked for radiation after every mission. NAST members carefully monitored their clothing for contamination. Frequently the snow around a hit site was contaminated by minute radioactive particles, and mukluks or pants could be easily contaminated. Any item of clothing which produced a reaction on the meters was immediately removed. Wrapped in plastic for security during transport, the material was later shipped to WRNE in Manitoba for disposal.

PROGRESS ASSESSED

The scientific team had recovered satellite fragments. Now, the first steps could be taken towards completing the jigsaw puzzle that Cosmos 954 had become. Each fragment, when studied and analyzed, told more of the story of how the satellite re-entered, burned and broke up. This information improved the search team's ability to predict the locations of other satellite debris.

Simply stated, the probable position of a satellite fragment depended on its

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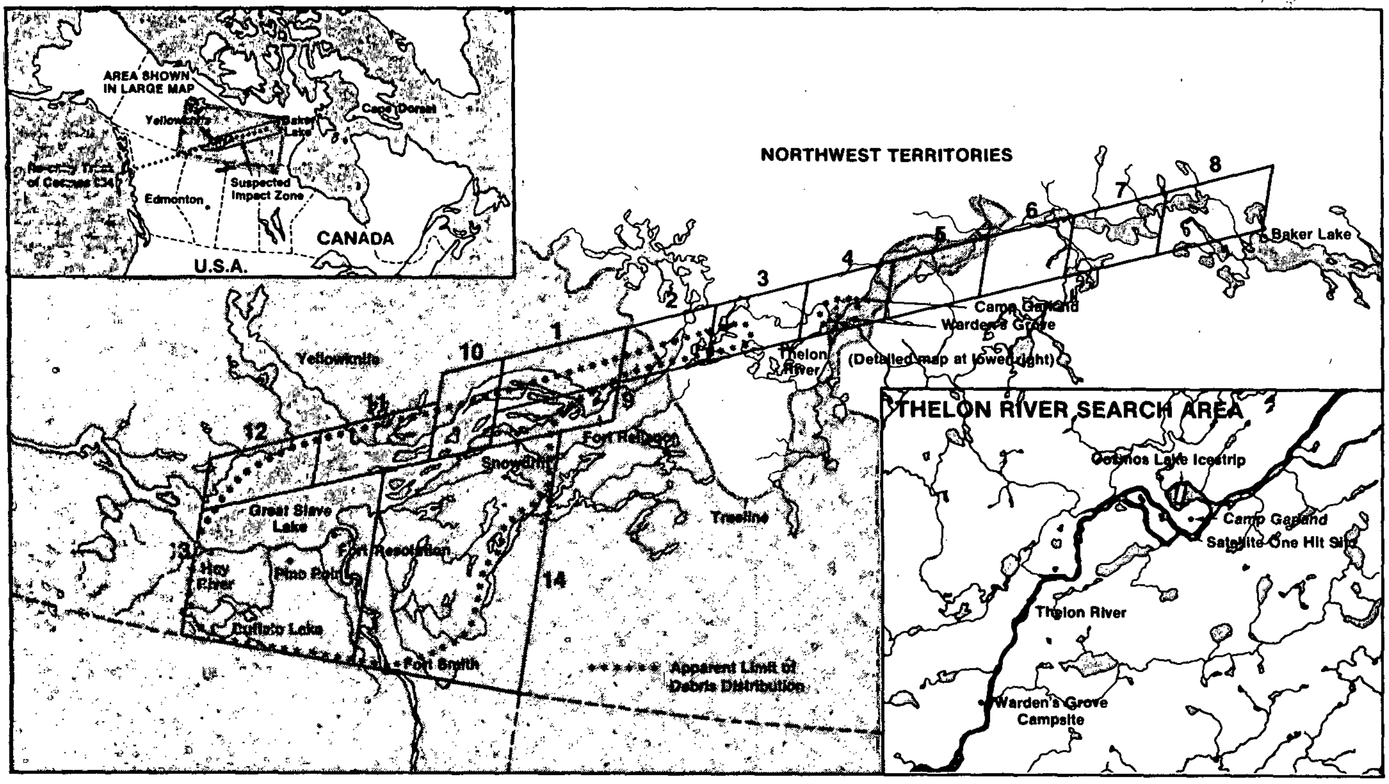

THE AREA OF SEARCH FOR COSMOS 954

density and its shape. The scientists expected the lightest pieces with the largest surface areas to have the greatest resistance against the air, and to fall short in the westernmost section of the re-entry zone. Dense pieces with minimal drag would have travelled farther downrange, to the vicinity of Warden's Grove or farther.

The military commander now decided to enlarge the search area. With so many small hits in Sector One, two more sectors (numbered nine and ten) were added to the search area at the westernmost end.

By Jan. 31 the *Hercules* search aircraft had completed their general search of all ten sectors, and all hits created a "footprint" within a narrow ten km-wide strip, right down the centre of the predicted re-entry path.

However, neither the aircrew nor the scientists were satisfied with the accuracy of the grid patterns flown by the *Hercules*. The navigation problem was just too great to guarantee a properly spaced search pattern over the entire area. On February 1 the commanders attempted to resolve this problem by flying three *Hercules* in a "V" formation, with the aircraft 200 metres apart. The planes flew up and down the entire length of the prime search area, in the hopes that all the prime terrain would be covered without any troublesome gaps.

The results were mixed. The spectrometers detected several more hits that day, but the pilots found that the strain involved in keeping such a tight formation for hours on end was extremely tiresome. The experiment was abandoned.

On February 2, the Americans flew in the solution to the navigation problem — a microwave ranging system (MRS). The MRS consists of directional beacons which are placed on two high points of land 20 to 50 km apart. A receiver/computer mounted in the aircraft receives the two signals and, using triangulation principles, monitors the exact position of the aircraft and enables the pilot to fly along a specific path.

Accurate coverage was now assured, and hits could be pinpointed to within 200 metres.

The beacons were placed in position in Sector One by helicopter, and on Feb. 3 the MRS went into operation. From that point on one MRS-equipped *Hercules* aircraft flew a 20 to 50 km square area each day. It would clearly take weeks to cover the entire search area at this rate, but at least it would be covered accurately and completely.

Search and recovery operations continued at the eastern end of Great Slave Lake throughout the first week of February, and on Feb. 4 the scientists were ready to recover the 200 R/hr fragment. The U of A technicians had constructed a lead container (nicknamed "the pig") weighing more than ½ of a ton.

That morning, with Defence Minister Barney Danson and 30 members of the media observing, a recovery team dragged the pig from a helicopter and using tongs quickly put the source into the pig.

The observers obtained a clear idea of the problems involved in the search. They spent 1½ hours flying to the site, then stood in the open in −40°C temperatures and high winds to watch the recovery operation. Cameras froze, and when bare flesh touched metal, it stuck. It was not an enjoyable experience.

RIDDLE SOLVED

During this week, the Baker Lake search detachment was experiencing its share of problems. The scientific team had flown into Satellite One again on Jan. 31. Through the winter's worst blasts of icy cold and wind, the scientists dug out the drift-filled crater in an attempt to find out what was below. Gas-powered ice augers froze in the bitter cold, and the team reverted to Inuit ice chisels to chip through the metre of ice. Underneath the scientists found a few centimetres of water and then sandy river bottom, but no sign of radiation.

This left them thoroughly puzzled. The only way the light strut-like rods

LWKG

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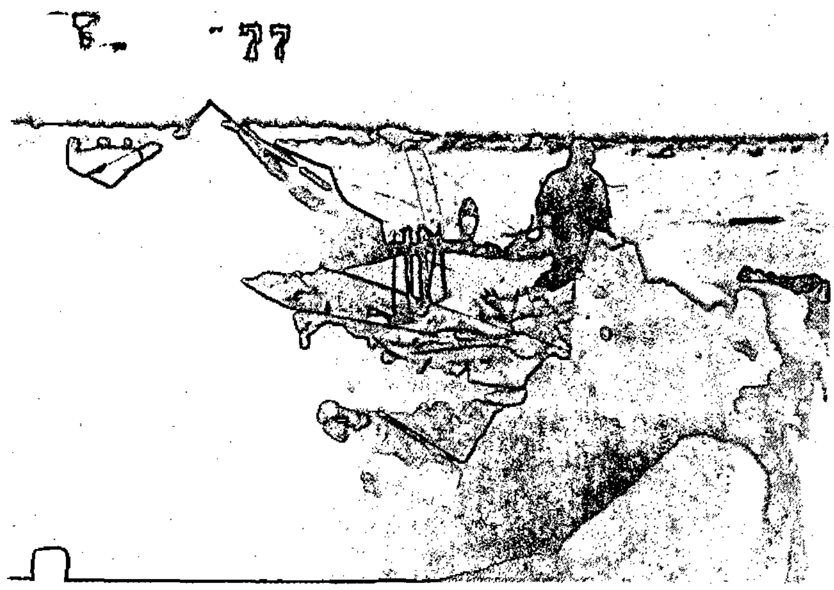

The Baker Lake search team spent a night in tents beside the Satellite One hit site. Red tape in background marks the contaminated area. (EG&G photo 1549-25)

LCol Donald Davidson and two scientists cook rations from their survival kit during night at Satellite One. (EG&G photo 1550-10).

found on the surface would have been dragged so far downrange was by something dense. But where was the dense object?

The search commanders had already considered this question, and plans were in the making for a detailed search of the entire area. There were even thoughts of damming the Thelon River in order to study the river bottom.

With an extensive search in mind, Col Garland directed LCol Davidson to pick a site for a landing strip and a forward base camp.

As the scientists continued taking their measurements on the river, LCol Davidson checked a nearby backwater-cum-lake (soon to be known as Cosmos Lake) for its feasibility as an airstrip. Then time ran out. Leaving M/Cpl Pat Callaghan, a rescue specialist, and an RCMP constable to guard the site, the team flew back to Baker Lake.

The next day 450 Sqn maintenance crews fought the bitter cold to keep the *Chinook* serviceable, and a day later the team returned to the site to take more measurements.

On February 3, a *Twin Otter* and a second *Chinook* (recently arrived from 450 Sqn headquarters in Ottawa) carried the scientific team into Satellite One. After more hurried measurements, the scientists packed up and returned to the shut-down helicopter.

With everyone loaded in, the pilot attempted to start up. One rotor turned; but the other would not budge. Eighteen people faced a night outside in the middle of the Arctic winter.

This sort of predicament was exactly why rescue specialist Pat Callaghan was there. As darkness enveloped the scene and the temperature plunged, Callaghan instructed the Canadian and American scientists, the aircrew and NAST member Pte Mona Wilson to quickly erect a second Arctic tent. (Callaghan and the RCMP constable already had one set up).

Soon the search team divided into two groups (smokers vs non-smokers) and settled into their tents to a meal from the aircraft survival pack. It was a memorable experience for everyone, particularly for the American scientists, who had been working in balmy Las Vegas ten days before.

The aircraft breakdown was a blessing in disguise. It meant the scientists could spend all of the next day at the site, while LCol Davidson completed his ice thickness tests and plans for the airstrip at Cosmos Lake. By the time a *Twin Otter* returned to pick up the search team, the scientists had confirmed that nothing lay beneath the ice.

That night Defence Minister Barney Danson flew in to Baker Lake with senior officers from Edmonton to assess the situation. The search commanders also brought the results of laboratory tests conducted in Edmonton on Satellite One snow samples. It contained lithium, an element used in the shielding of nuclear reactors. When it contacts water, lithium reacts violently (in the same manner as sodium). The violent reaction of lithium and snow had created a large puddle which when refrozen caused the huge crater at Satellite One. The lithium then dissolved in the reaction. The mysterious crater was explained.

CAMP GARLAND BEGINS

The Thelon River area was becoming the focal point of search activity, particularly as the MRS search completed its survey of the western Great Slave Lake area and moved downrange. It was clear that a camp and airstrip at Cosmos Lake were essential not only for logistics support, but also as an operating base for the recovery teams and the *Twin Hueys* they used to check the hit sites.

On February 5, Operation Morning Light moved into a new phase. The Baker Lake operation began to close down, and Cosmos Lake began to build up. That day, 10 pioneers and a medical assistant from the 1st Battalion, Princess Patricia's Canadian Light Infantry, plus a bulldozer driver from 1 Combat Engineer Regiment flew in by *Chinook* from Yellowknife to set up the first tents of what was to become Camp Garland.

The bulldozer needed to clear the 1,600 metres of ice airstrip on Cosmos Lake arrived next; dropped from a low flying *Hercules* by LAPES (Low Altitude Parachute Extraction System) on February 6. Cat driver M/Cpl Sid Behme immediately went to work. Snow, wind-driven until it packed like concrete,

Two NAST members check the low radiation levels around collected debris found at Satellite One.

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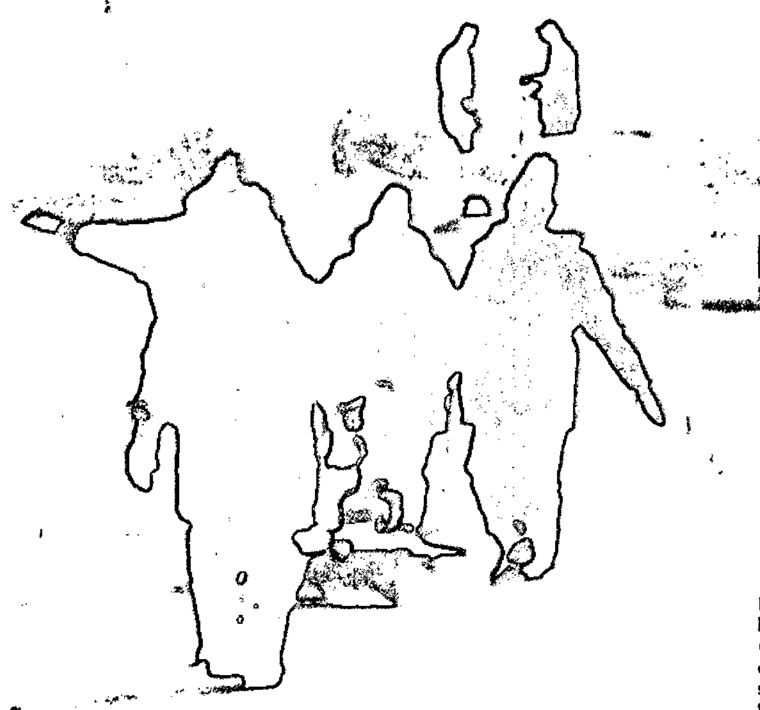
slowed the operation. Another bulldozer and two more drivers would be required before the strip would be completed on Valentine's Day. (See Camp Garland story on page 17).

When the first 424 Sqn *Buffalo* aircraft touched down on the ice strip on February 15, three scientists were aboard, keen to unpack their equipment and get on with the detailed search of the area. Camp Garland was about to become operational.

During the next six weeks, up to 100 people made Camp Garland their home. *Twin Huey* helicopters operated from an inflatable hangar, carrying out detailed searches for hits in the area and taking scientists to them.

In addition to normal military communications systems, DND contracted with Telesat Canada to provide a satellite communications terminal at the camp. The 955 kg dish-type antenna was flown into Cosmos Lake on March 3, and within 48 hours the scientists and military commanders at Camp Garland



could discuss plans and problems with Edmonton (or anywhere else in North America) simply by picking up a phone.

NEW DIMENSIONS

In the meantime, there had been dramatic developments elsewhere.

Even before Camp Garland officially opened, the search had taken a new direction. On February 10, a 408 Sqn *Twin Huey* with a two-man scientific team was diverted from the search area to the western end of Great Slave Lake to check a peculiar hole in the ice. After inspection, scientists attributed the hole to natural causes, and the helicopter returned to the main search zone. But as it flew above the Snowdrift area, the radiation monitoring equipment started to register hits.

Circling low, the crew soon discovered a dozen hits on the ice of Great Slave Lake, five to eight km northwest of Snowdrift. The low flying helicopter had discovered radiation sources in the low milliroentgen range, too weak to be picked up by the higher flying *Hercules.*

That afternoon, recovery teams flew to this new site. They discovered many tiny particles, ranging in size from microscopic to peppercorn.

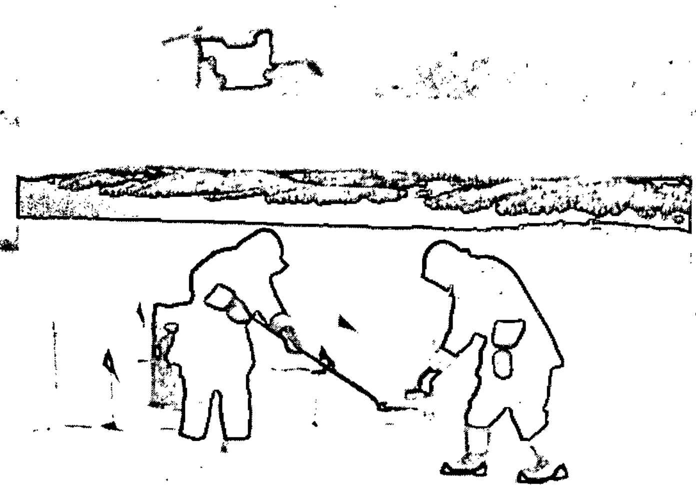
Later testing indicated that these minute pieces were fissionable material — the reactor core.

Over the next few days search missions along the south shore of Great Slave Lake turned up more low-range hits.

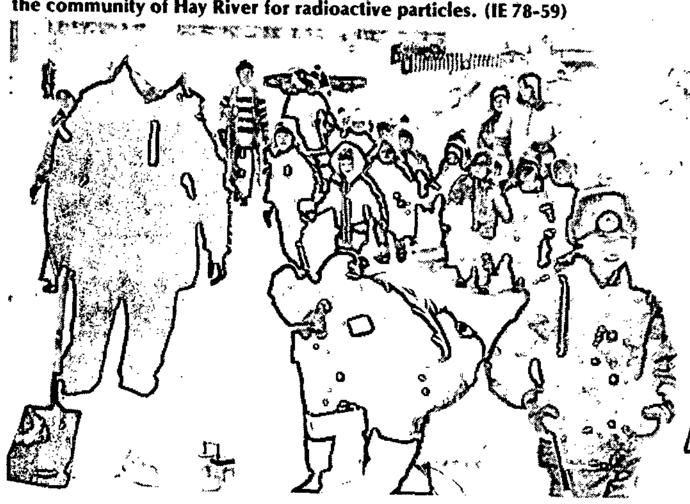
At last the searchers had an inkling of what had happened to Cosmos 954's reactor. It had possibly burned up on re-entry, but without complete combustion. Instead, minute pieces had fluttered down from the upper layers of the atmosphere. These radioactive particles, caught in the northerly winds of the night of Jan. 24, had drifted southwards to "dust" a huge area south of the predicted re-entry path.

The search effort was now aimed at defining the boundaries of the area of dust contamination. On Feb. 21, helicopters discovered low level radiation hits near Hay River and Fort Resolution. By the end of February the boundary of the additional contaminated area was defined. It contained 80,000 sq km from Hay River in the west to Buffalo Lake in the south, and east to a line drawn roughly from Snowdrift to Fort Smith.

The commanders of Operation Morning Light now faced a new problem. A huge area was contaminated by a fine sprinkling of radioactive particles, spread in random fashion, frequently hundreds of metres apart.



Left. Search team drags its equipment across the wind-swept surface of a lake near Cape Dorset to investigate a suspicious crater in the lake ice. (OPML 27-18). Above. In the latter stages of the search, recovery teams checked shovelfulls of snow for radiation, and deposited contaminated snow in garbage cans. (EG&G photo 1498-14). Below. NAST members check the community of Hay River for radioactive particles. (IE 78-59)



LKG

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With the prospect of spring breakup in early May, neither time nor resources would permit clearance before the snow melted and the particles settled into the soil or the water of lakes and rivers.

AECB scientists recommended the search of all inhabited areas with ground teams to remove all contamination. In addition, *Twin Hueys,* capable of flying low and picking up lower radiation levels than the *Hercules,* would survey and clear all transportation routes within the area. Finally, the entire area would be divided into sectors and searched using the radiation detector-equipped *Twin Hueys.*

During the early part of March, Pine Point, Hay River, Fort Resolution and other southern Great Slave Lake communities were surveyed. In the vicinity of most of the communities the NAST team and scientists discovered a few dozen particles in the micro-roentgen range. There was no question of isolating each particle; a small amount of snow was simply shovelled into a plastic bag and carried away for disposal.

During March the search continued. There were some exciting moments when Inuit hunters on Baffin Island reported discovering a huge re-frozen crater on a lake 25 km northwest of Cape Dorset. The site was on the satellite track, and trajectory experts concluded that it was possible for an aerodynamically-shaped piece of Cosmos 954 to skip along the upper layers of the atmosphere and crash to the earth that far away from the other debris.

A *Twin Huey* helicopter was quickly dismantled and airlifted to Cape Dorset, where it flew a military/scientific team to check the site. No radiation was discovered in the area. After studying the site carefully the scientists (including ice experts from the National Research Council) concluded the refrozen crater was a natural phenomenon.

WINDING DOWN

Along the main satellite track itself, several more hits (including one of 500 R/hr) were made between Great Slave Lake and Cosmos Lake. These were quickly picked up. By late March, it was apparent that the Cosmos Lake area was cleaned up, and the time had come to close Camp Garland. On March 29, the last flight departed from the ice strip that had been built with such great effort seven weeks before.

Even before this, the American element of the Operation Morning Light team had started winding down. At its peak, the American contingent numbered 115 people. Their knowledge and assistance had been invaluable, particularly during the early stages of the search. The last American scientist left Camp Garland on Mar. 7, and the last American gamma ray spectrometer was flown out on March 21.

The next day the Canadians bid farewell to the last group departing for their home base at Las Vegas. Canada's appreciation was expressed that day in a message from Prime Minister Trudeau to President Carter.

During April, a complete assessment of the operation took place in Edmonton and Ottawa. The search objectives had been met: all radioactive debris identified by the *Hercules* search aircraft had been picked up (from more than 60 sites); all communities and campsites plus their environs had been cleared, as had all transportation routes in the search zone. Radiation sources being recovered were now in the same strength range as the earth's background radiation. In addition, the scientists calculated that the radiation from the satellite core pieces was decaying rapidly.

The danger to human and animal life had been minimized, and the search effort was now producing limited results. The time had come to reduce the military recovery operation.

On-going monitoring programs will continue throughout the spring and summer of 1978. As has been the practice thus far, DND and other federal departments and agencies will continue to support AECB, which is responsible for protecting the health, safety and security of Canadians with regard to nuclear energy.

Operation Morning Light has been an expensive venture for Canada. At the time of writing, DND expenses alone stood at more than nine million dollars.

There are hidden costs as well. CF aircraft flew more than 4,700 hours on search and resupply missions, taxing aircrew and the people who support them, and disrupting long-planned exercises and maintenance schedules.

In return, everyone involved has gained superb operational experience under extremely difficult conditions.

THE WORLD WATCHES

Have you ever tried to answer seven telephones at once? Two Canadian and one American information officers attempted that during Operation Morning Light - not just once, but for seven straight 20-hour days.

When Cosmos 954 crashed in the N.W.T., the world's news media considered it the hottest thing since sliced bread, and for two weeks it was front page news. Several score national and international reporters invaded Edmonton and Yellowknife to cover the search. At the same time, media queries were phoned in constantly from as far away as Australia, Europe and Japan.

So many reporters tried to use the telephones to gather and pass information that their activities threatened to affect operations. So a section of CFB Edmonton's aircraft passenger waiting room became a media centre. There, Majors Vic Keating and Wally West and U.S. DOE information officer Dave Jackson handled media queries round the clock. All seven available phones were frequently busy, and CFB Edmonton telephone operators had to keep media waiting lists.

The story was so big and complex that the major television networks had several news teams reporting on the search, some using Learjets to fly them between Edmonton and Yellowknife.

In the midst of this, information officer Capt. Craig Mills returned to Edmonton from a six-month tour in the Middle East, not even aware that a satellite had crashed. Before he had his bags unpacked, he was called in to help.

As the days passed and media interest increased, more information officers were sent to Edmonton and Yellowknife to assist the initial team. At the height of the operation, seven Canadian and two American information officers were involved.

At Yellowknife, Maj. Wally West briefs the news media about the six adventurers at Warden's Grove. (News of the North photo)

WKG

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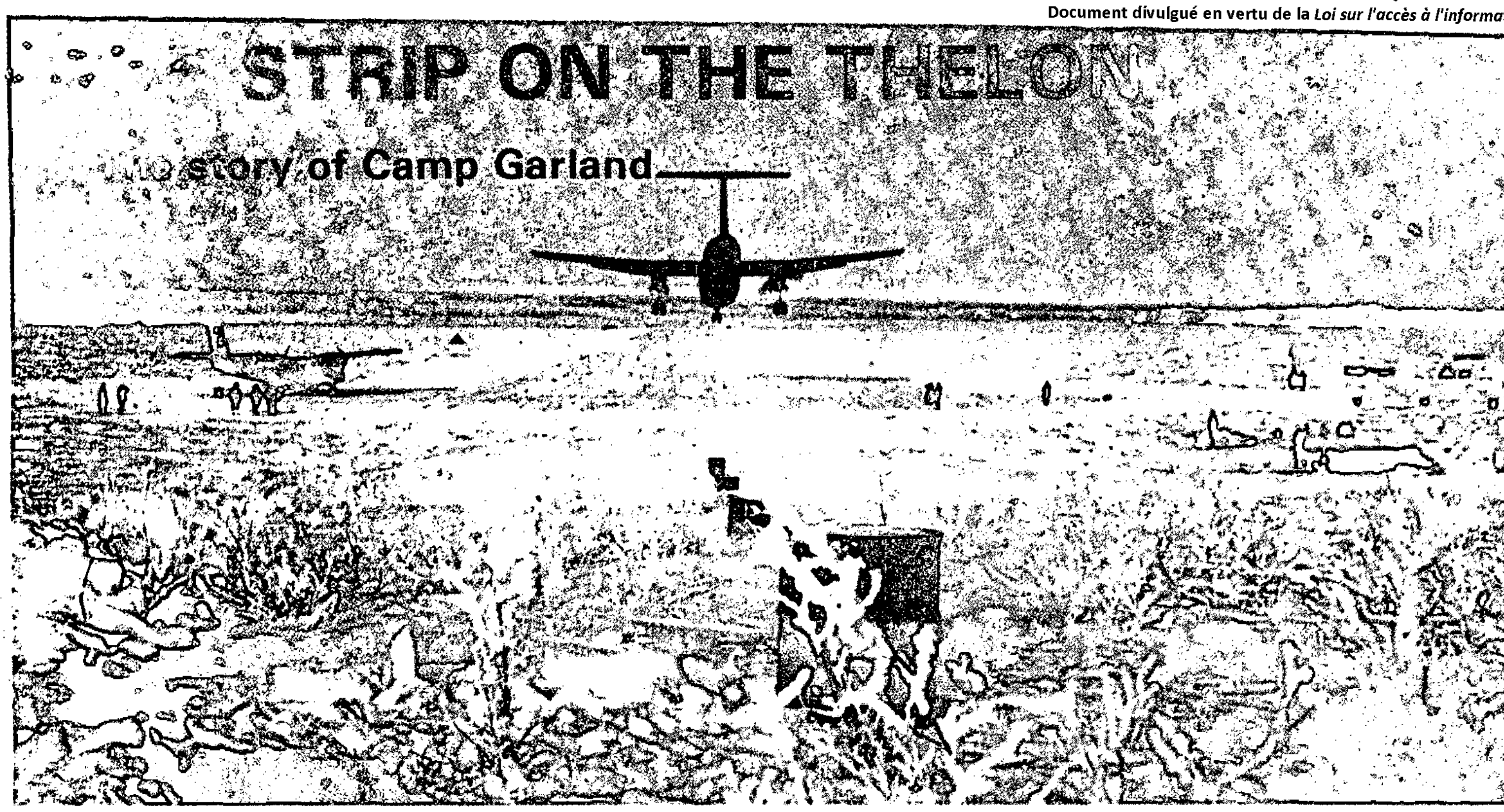
STRIP ON THE THELON

story of Camp Garland



by Maj. Bill Aikman

A small group of Canadian servicemen now scattered on bases from Chilliwack to Trenton know what it's like to live in the eye of a hurricane.

They've experienced a kind of loneliness and isolation on the tundra in midwinter that even Robert Service would have been hard pressed to describe.

For while the world clamoured to learn more about the chunk of Cosmos 954 that plummeted onto the Thelon River, 30 servicemen lived and worked a few minutes walk from the crash site. Their task — to build an ice runway long enough to accommodate *Hercules* aircraft.

The airstrip was an operational necessity. Behind the decision to build it was the suspicion that the satellite's nuclear core might be found nearby. The recovery team, which had been making 800 km round trips to the crash site by helicopter, needed better access and more time on the ground to conduct investigations. And so Camp Garland, named for the commander of Operation Morning Light, came into existence.

It was to be an almost solitary existence for the first ten days. Bad weather sometimes prevented resupply helicopters from reaching the site, and the temperamental ionosphere prevented radio communications for days at a time. So, unaware of what was happening beyond the low hills that surrounded the camp, each man carried on, fighting his own private war against the piercing cold.

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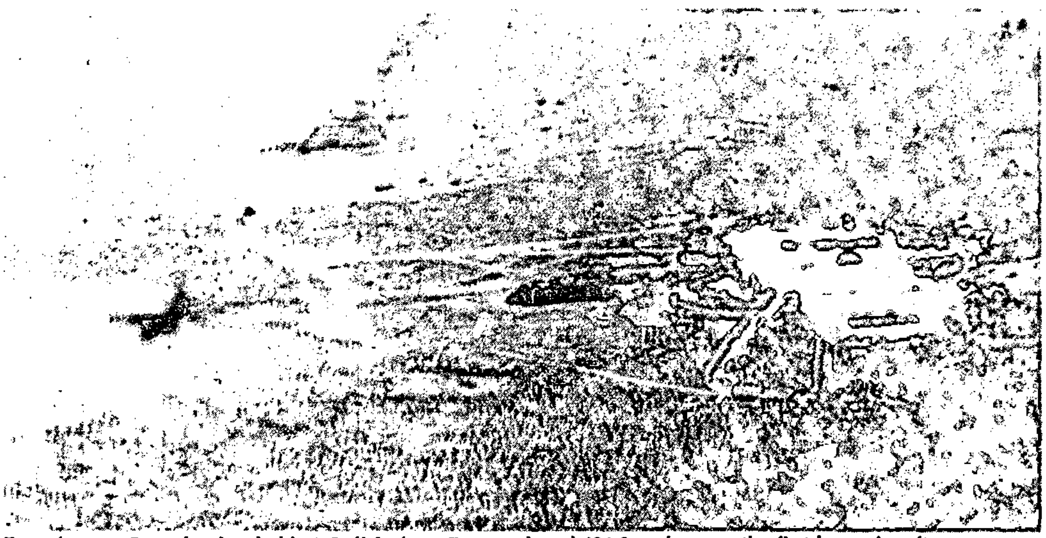
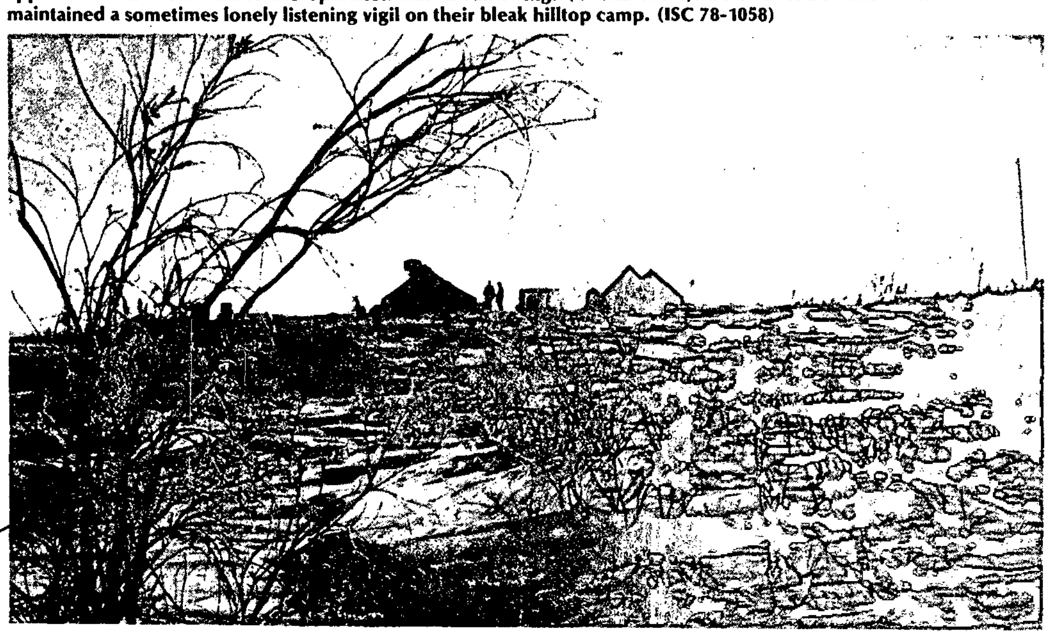


Top of page. Over the threshold. A Buffalo from Trenton-based 424 Sqn. became the first large aircraft to land on the Cosmos Lake strip Feb. 15. The whole camp turned out to watch the touchdown and greet the arriving scientists. (ISC 78-1051) Above. Camp Garland and the Cosmos Lake airstrip as they appeared from the air while the operation was in full swing. (OPML 071-2). Below. ATCCT members maintained a sometimes lonely listening vigil on their bleak hilltop camp. (ISC 78-1058)



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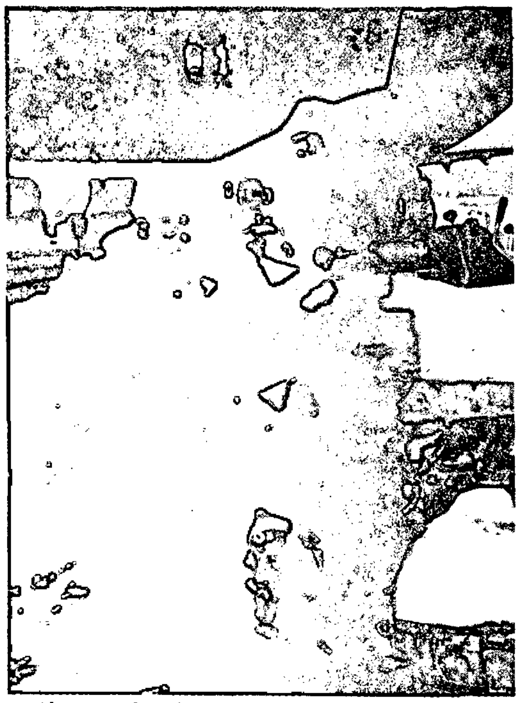
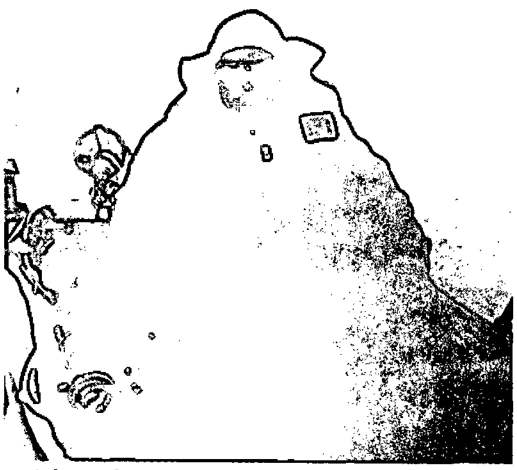


Above. Cpl Andy "S.B." Anderson and M/Cpl Duncan MacIntosh (on dozer) worked in frigid weather to clear 1,600 meters of runway. (ISC 78-1052) Below. M/Cpl Sid Behm proudly sits aboard his dozer moments before the first large aircraft landed on the runway behind him. (ISC 78-1053)



Below. Flags, taped music, the roar of an aircraft engine, and a deft slice with a snow knife marked the official opening of the airstrip. While the new camp CO, LCol Steve McGowan, left, and camp residents watched, LCol Donald Davidson (the outgoing camp commander) and M/Cpl Behm cut a piece of fluorescent tape. (ISC 78-1088)

Adventurers from Warden's Grove pay a visit by dog team to the fully operational Camp Garland, providing a diversion for scientists and CF personnel. Having neighbours in the midst of Arctic isolation was a great luxury. (ISC 78-1082)

Two *Chinooks* pounded their way to the Satellite One site February 5, carrying men and equipment for the project. Under the command of Lt Ted Bain, 10 pioneers and a medical assistant from the 1st Battalion Princess Patricia's Canadian Light Infantry, and a heavy equipment operator from 1 Combat Engineer Regiment tackled the job of setting up camp on a bleak hillside.

The next morning, the first D-4 bulldozer was jettisoned from a *Hercules* cargo hold and skidded onto the snow covered surface of a nearby river backwater. Within seconds the pioneers were unstrapping the dozer from its platform and filling it with fuel in order to start it before the Arctic cold could penetrate its engine block.

Less than five minutes later, M/Cpl Sid Behm, the heavy equipment operator, was driving across what would soon be called Cosmos Lake. Once started, the dozer was not shut off for weeks.

Sid Behm's first job was to clear a campsite and a network of roads around it. It was not an easy task, for among the stunted trees that fought for survival this far north the snow was one to two metres deep.

The pioneers began to mark out the airstrip, which fitted neatly on the lake between two low-lying hills. Using a 32 metre (100 ft) piece of rope and a compass bearing, they measured out 1,600 metres of runway.

Later that day another *Chinook* arrived from Baker Lake, carrying the camp commander, LCol Donald Davidson, supply and vehicle technicians, a rescue specialist and a second heavy equipment operator, Cpl Andy Anderson.

Aware of the urgent requirement to clear the strip, the two drivers worked continuously from first light until after dark.

It was not so much the darkness that stopped them as the cold. The -30 to -40°C temperatures made sitting on the high, exposed seat of a cat thoroughly uncomfortable.

During the first three days of operations the winds gusted to 60 km/hr, driving snow against the drivers faces and through their heavy clothing. Each night the men returned to the tent damp from snow that had melted inside their parkas, and stiff-jointed from sitting still in the cold all day.

The rescue specialist and medical assistant took turns manning a tent beside the slowly growing airstrip, where the cat drivers occasionally stopped to talk and get warm.

Sid Behm and Andy Anderson not only had to fight the cold to do their job, they had to fight the snow. Driven by the wind, the ¼ metre to a metre deep snow on the exposed lake was as hard as concrete. It took at least two cuts to clear one blade width. By Feb. 9, only 300 metres of the strip had been cleared.

Late that day a second bulldozer was dropped, and the pace picked up. On Feb. 11 the strip measured 800 metres. On Feb. 12, the drivers reached 1,000 metres. M/Cpl Duncan MacIntosh arrived the same day to help share the driving duties. The small advance party at Camp Garland began betting on when the first *Hercules* would touch down.

While the runway grew, other problems began to appear. At one metre thick, the ice barely met the minimum landing standards for a 65-ton *Hercules*. In radio conversations with Edmonton, it became clear that the *Hercules* pilots weren't enthusiastic about landing under such conditions.

The construction party let time and weather solve this difficulty. When the surface ice lost its insulating blanket of snow the cold penetrated deeper, and

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Above. Hardpacked snow, wind-driven to the consistency of concrete, was difficult to move. Heavy equipment operators braved the extreme cold from dawn til after dark for eight days to clear the strip. (ISC 78-1062)

bit by bit the ice began to thicken.

But the bare ice was much colder than the water below, causing another problem. The ice temperature at the surface was -40°C. A metre below the water was 1°C. The ice began to contract and thermal cracks appeared. This, combined with the weight of the snow ploughed to each side, caused a narrow fault line to run right down the centre of the strip.

As the days passed, this crack grew to two and in some places three centimetres wide. Fearful that the fault could endanger aircraft operations, LCol Davidson ordered the cracks be filled. So for two days the pioneers combed the strip with jerricans, filling the cracks with a quick-freezing mixture of water and snow.

While the effort continued on the ice of Cosmos Lake, life carried on apace for the 30 persons living in the collection of tents that made up Camp Garland. During the day three cooks produced hearty meals in a modular tent which doubled as sleeping quarters.

Lt Mike Bolohan from 1 Construction Engineering Unit at CFB Winnipeg bounced between the tent and runway studying the feasibility of using an ATCO ablution trailer at the site, tabulating ice thickness and researching lakebed information.

A short walk away from the main tent, on the highest point of land near the camp, stood the tents of the Air Transportable Communications and Control Team (ATCCT).

ATCCT is a Trenton-based organization which has the capability of setting up the communications, radar and airfield lighting systems at forward airheads. Originally deployed to Baker Lake and Yellowknife, several of its men flew to Camp Garland on Feb 7. Soon the camp had communications with the outside world, an internal VHF radio system, and a TACAN radar beacon to assist aircraft in reaching the airstrip.

The radio link was tenuous. In this part of the world the aurora borealis dominate the skies, frequently playing havoc with communications. On Feb. 12 the nightly display of eery lights reached its height, and at the same time fouled communications. For the next 48 hours, the communicators couldn't raise another station with either morse or voice transmissions.

The weather also caused difficulties again. The sky clouded, turning the Thelon River basin into a horizonless grey world. Ice fog settled in. No helicopter would be able to navigate its way to this isolated post.

Late in the afternoon of Feb. 14 LCol Davidson walked the length of the strip with LCol Steve McGowan, CO of 408 Tactical Helicopter Sqn, who was to take command of Camp Garland upon its completion. (Or, as he commented to C-130 pilot Davidson, "After the first *Hercules* goes through the ice".) All but 200 metres were complete, and the thermal crack was patched up.

When a *Hercules* aircraft flew low on yet another LAPES delivery mission, the camp commander radioed that the airstrip would be ready to receive heavy aircraft the next day.

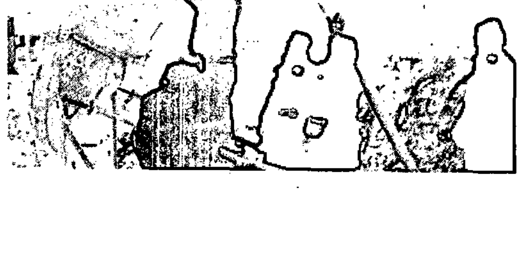
That night, well after dark, three cold and hungry but jubilant bulldozer operators burst into the dining tent. The strip was complete.

Shortly after noon on February 15, a 424 Sqn *Buffalo* aircraft from CFB Trenton touched down on Cosmos Lake. When it taxied to a halt in front of a cheering group of spectators, out stepped a three-man scientific team, led by Dr. Norm Bailey. Soon pallets of scientific equipment were being offloaded and towed by bulldozer to the main tent. The next day the first *Hercules* landed, carrying more scientists and their equipment.

Camp Garland had entered its second phase — the downrange search and recovery centre for Operation Morning Light.

Above. C-c-c-c-cold temperatures made keeping warm a priority. Camp members inspect a temperamental Herman Nelson heater outside the mess tent. (ISC 78-1071)

Above. Lt Mike Bolohan of 1 CEU gamely dips his hand for a sample of water from Cosmos Lake. A couple of minutes later he had to break surface ice with a pick to continue the job. (ISC 78-1060). Below. Camp Garland's communications problems were solved by a Telesat Canada earth station. In the camp's early days, communications were restricted by the whims of the ionosphere. With the introduction of the terminal, anyone with a telephone could talk to Camp Garland via Canada's Anik satellite. (ISC 78-1087)



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BAKER LAKE

The Search Moves Downrange

by Maj. Bill Aikman

How do you explain the concept of a nuclear-powered satellite to people who have no words to describe a satellite, let alone nuclear radiation?

The task demands some effort and imagination, as LCol Donald Davidson discovered when he spoke to several hundred Inuit people in a Baker Lake school gymnasium last winter.

LCol Davidson was at the school to tell the native people about the poten-tial danger of Cosmos 954, the [illegible] satellite that had crashed in the [illegible]. Pausing frequently while an [illegible] translated his words into Inuk[illegible], Davidson explained wh[illegible] sonnel and scientist[illegible] upon the communit[illegible] and why airplanes and helic[illegible] constantly flying overhead.

His audience was concern[illegible] wanted to know what radiatio[illegible] do to the caribou, to the fish [illegible] them. In the end they accept[illegible] explanations and welcomed the st[illegible]gers into the community. It was an excellent example of community operation at work.

Three days later, the entire search team was back in the gymnasium, this time to watch a native drum dance put on in their honour.

Such was life at Baker Lake. During 12 days of operations, the Morning Light detachment developed a character all its own.

The detachment was set up January 26 with the arrival of LCol Davidson, three NAST members and a mixed Canadian-American scientific team. They began operations in the only place in town big enough to accommodate them — the Iglu Hotel.

The Iglu Hotel is a large quonset hut owned by the village. It contains double rooms and bunkhouse-style sleeping quarters. No alcoholic beverages are sold, at the request of the Inuit community.

The new customers were surprised by the $63-a-day room and board charge, until they realized that everything they ate had to be brought in by air freight. Later, as the search team grew and overtaxed the hotel's resources, a CF cook joined the staff to help prepare meals.

Top. As darkness settles over Baker Lake, a *Chinook* helicopter returns from Warden's Grove. (E.G.G. 1455-04) Above. NAST member Pte Mona Wilson dresses against Arctic cold. (E.G.G. 1479-4)

The scientific team began their search January 27, leaving behind Capt John Lyne, of the NAST team, and team member Pte Mona Wilson to talk to school children about all the puzzling activity. Their school visit sparked the request for an explanation to the whole community.

Pte Wilson's presence intrigued the Inuit girls, who were astonished to discover that women serve in the Forces. The young Edmonton servicewoman spent more time answering personal questions than queries about satellites.

On the same day LCol Davidson spoke to the community, word was received that pieces of Cosmos 954 had been found on the Thelon River. The Baker Lake detachment was ordered to investigate the site, and the next day LCol Davidson headed the search party

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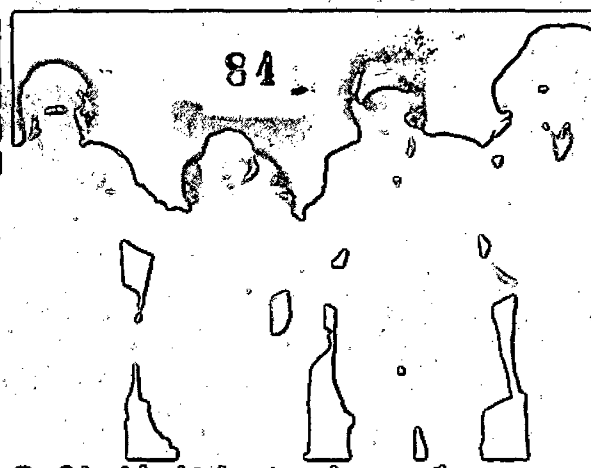
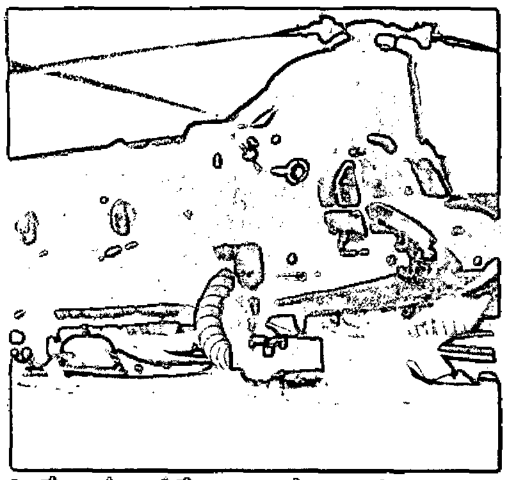
Above, LCol Donald Davidson explains the Comos 954 search situation to Inuit at Baker Lake. (E.G.G. 1458-45) Below, Herman Nelson heaters had to run for three hours before a *Chinook* would start. (ISC 78-2000)



Five Baker Lake detachment members were the first searchers to reach Thelon River hit site. Four pictured above are Paul Mudra, Pte Mona Wilson, LCol Don Davidson and Tom Crites (E.G.G. 1495-09) Below, Baker Lake community. Quonset hut at centre right is Iglu Hotel. (E.G.G. 1552-09)



to the edge of the mysterious crater.

The Baker Lake group travelled 400 km to the hit site in a *Chinook* helicopter.

Initially, 450 Sqn's powerful helicopters provided the best means of getting people and equipment into Satellite One. However, the long distances required that each helicopter be outfitted with three rubber fuel bladders; a situation which reduced the load capacity.

In addition, the *Chinooks* were operating to the limits of their capabilities in the cold Arctic environment. Helicopter serviceability problems and harsh weather plagued the operation for the next week.

The *Chinook* is a complicated aircraft. It has five transmissions and three hydraulic systems, which in cold weather require 14 to 16 man-hours of maintenance for every hour flown. In the Arctic winter, where rubber seals deform and oil freezes solid, the strain was just too much.

It was tough on the maintenance crews as well. Working without a hangar in temperatures that dipped below -100°C with the wind chill, the technicians were restricted to 2½ minutes work in the open at a time.

Even simple procedures such as starting the aircraft engine were extremely difficult. The heat from a Herman Nelson heater had to be directed into the engine and transmission compartment for three hours before a cold-soaked engine could be started. Any less time would damage the seals.

Such maintenance difficulties restricted flights to Satellite One to every second day.

While the technicians performed their heroics at the Baker Lake airstrip, the scientists developed methods of photographing underneath the ice in preparation for the search to come on the Thelon River.

Pte Wilson was busy as well; gathering souvenirs for the cub pack she leads and arranging pen pal relationships between children in Baker Lake and Edmonton. She even acted as an impromptu recruiting officer, making a return trip to the village school to explain more about life in the Forces.

But Pte Wilson never allowed these activities to interfere with her NAST duties. She was one of three people who made the trip to Satellite One on every expedition up to the formation of Camp Garland.

With the decision to open up a base camp at Satellite One, the Baker Lake detachment lost its raison d'être. The detachment closed shop with a grand finale — a visit by Defence Minister Barney Danson.

While detachment members rushed to buy souvenirs and thank the Inuit people for their hospitality, Pte Wilson got ready to leave with something extra. She had been "adopted" by 450 (West) Sqn. And she proudly displayed the squadron crest to prove it.

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by Lt. Wendy Tighe

These men, the ones who work at CFB Edmonton loading big pallets with 45-gallon drums of fuel, skidoos and sometimes even bulldozers, must have been up all night.

It took ten of them six long hours to strap together 9,100 kg of aviation gas, hoist the loaded pallet onto a roller-equipped truck bed with a crane, drive it to a waiting *Hercules,* hydraulically lift the truck bed up level with the landing ramp, and then slide the pallet onto the aircraft cargo rollers and strap it down again.

Now the same men are at work under the bright lights of the nose dock in an old alert hangar, carefully packaging a D-4 bulldozer with layers of two by fours and horsehair, reams of nylon straps and heavy metal buckles.

Late this afternoon the "cat" will be delivered to the Canadian Forces' Cosmos Lake base camp site in the Northwest Territories, only metres from a spot where a chunk of the Soviet Cosmos 954 satellite still sticks out of the snow.

It will be delivered at a speed of 130 knots from a *Hercules* flying about one to two metres above a frozen lake. Three large parachutes will bring it to a snow-spewing halt. Minutes later, somebody will drive it off the pallet and put it to work, stopping only long enough to reassemble the blade.

The fuel load now aboard the aircraft faces a similar fate. In a few hours it will be dropped on Great Slave Lake alongside the tiny community of Fort Reliance.

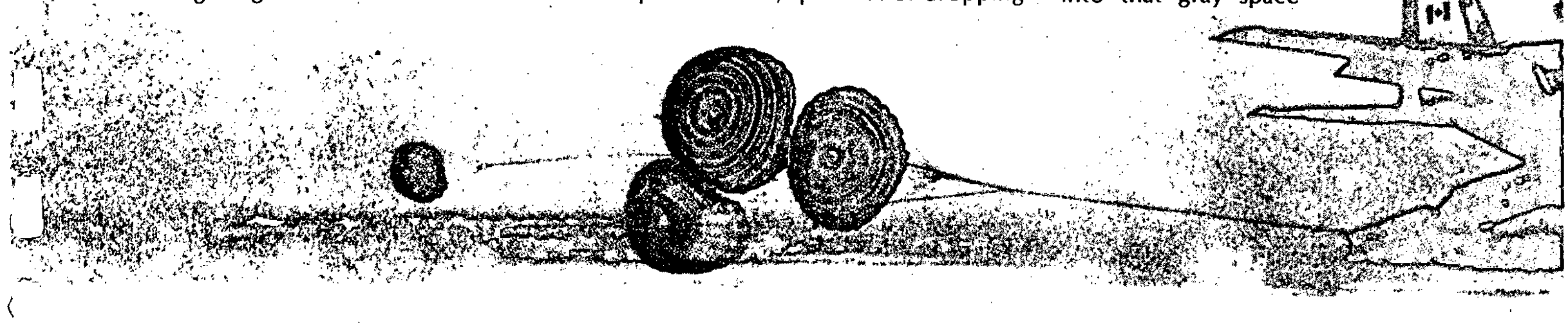
Several *Hercules* crews at CFB Edmonton's 435 Squadron are trained in the quasi-science, quasi-art of dropping cargo via the Low Altitude Parachute Extraction System (LAPES).

To the layman, a routine LAPES drop is a death defying spectacle. The sight of all that ground coming up under all that aircraft is enough to leave one permanently bug-eyed.

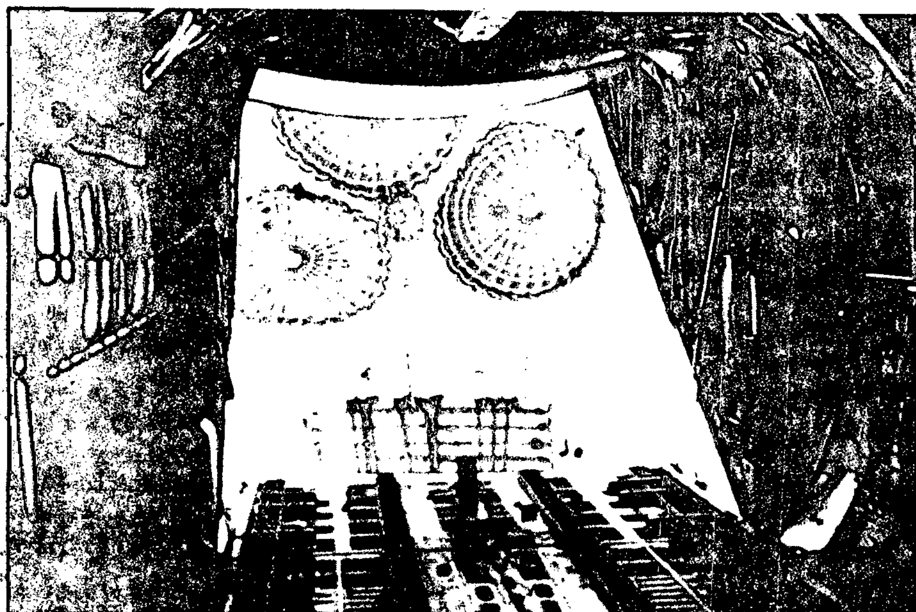
To the pilot it's a skill; a matter of keeping the plane level, nose slightly up, wheels off the ground. It's a marriage of experience and aerodynamics; a business where efficiency outweighs the risks.

To those on the ground, a LAPES drop often means the difference between survival and comfort, getting a job done or sitting idle; especially in the north.

And that's where flight 6840 out of Namao is headed. The crew from 435 Squadron scrambles aboard the Herc and minutes later it is moving along the taxiway, through snow that has drifted over miles of open prairie, past the hangar line and into that gray space



Above and Below. A fuel-laden pallet kicks up snow as it shoots out of a *Hercules* flying feet above Cosmos Lake. These pictures were snapped at almost exactly the same moment by photographers on the ground and in the aircraft. (ISC 78-1046, E.G.G. 1594-31)



between night and morning.

The pilots, Captains Bob Lee and Mike Taylor, lift 68,000 kg of loaded aircraft off the runway, their hands working the throttle together.

Clouds obscure the flat earth below as the plane climbs and swings northwards. A great orange ball of a sun appears, prompting somebody to make a joke over the intercom about listening for the crack of dawn.

Breaks in the cloud cover reveal Fort McMurray, and beyond it a changed landscape. Bald prairie has given way to rolling hills.

The loadmaster prepares a hearty breakfast for the six-man crew. They finish up as the landscape ahead begins to change again. Rocky hill tops, deep trenches and winding ridges spread in every direction, monuments to the relentless drive of the glaciers.

The lakes begin. Here they are called by polite surnames. Farther north men named them from experience, a not entirely pleasant experience as Lakes

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Disappointment, Desperation, Defeat and Perish describe.

Beyond the snow covered pockmarks of the small lakes is the big daddy in this neck of the woods — Great Slave Lake. And perched on a spit of land which juts into the broad expanse of McLeod Bay is Fort Reliance.

Four, perhaps five houses and a communications building make up this tiny community, augmented today by a yellow ski-equipped *Twin Otter* from 440 Squadron detachment in Yellowknife.

Smoke marks the drop zone on the lake below. Aircraft Commander Bob Lee is satisfied with the pre-drop arrangements, and the Herc makes a big circle before beginning a gradual descent.

In the cargo hold, loadmasters Sergeant Rick Grinham and Master Corporal Andy Robicheau have checked and rechecked the equipment; the drogue chute, the main chute and the loaded pallet. Their job now is to wait for the go ahead from the cockpit.

The once smooth-looking lake surface takes on a rippled appearance through the open ramp. The wind packs the snow like concrete up here, then sculptures it into shallow dunes.

The plane is low now. A quick exchange between the cockpit and the loadmasters and the drogue chute spreads out; bright red stripes taut in the cold, clear Arctic air.

Up front Bob Lee works the flight controls; keeping the aircraft level as the interval between the deployment of the drogue chute and the main chute stretches to ten seconds, then past ten . . . "Cut the drogue" is the terse order from the cockpit. The jettisoned canopy bursts away with a crack like a rifle shot, and milliseconds later the aircraft wheels cut through the hard packed snow surface. Something has gone wrong.

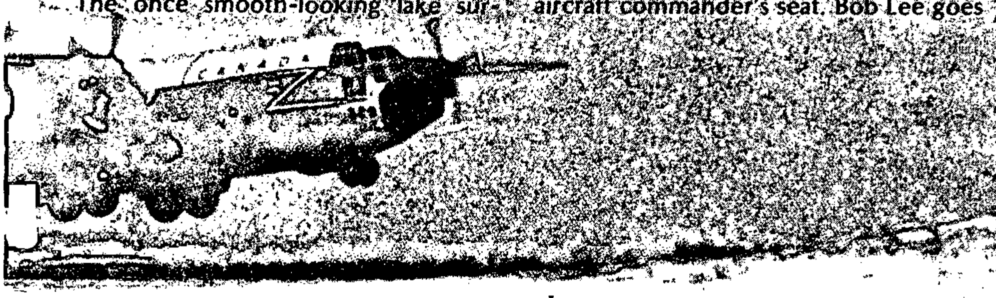
With a roar, four powerful engines pull the Herc off the snow and over the rocky ridge. Capt Don Ward, a Herc pilot who came along to see how a LAPES drop is done, slides into the aircraft commander's seat. Bob Lee goes back to the cargo hold to find out what the problem is.

The culprit, it seems, is a lynch pin that didn't pull out of the way to allow the drogue chute to haul the main chutes and the load off the ramp. Bob Lee decides to try the drop again.

Silhouetted on the open ramp, the loadmasters begin rigging another drogue. Behind them, trees, snow and sky turn topsy turvey as Don Ward and Mike Taylor mark time with big, lazy circles.

The chutes are checked and rechecked. Bob Lee takes command, and circles Fort Reliance one more time. Again the plane descends to 250 feet above the lake surface. The drogue chute unfurls and is pronounced "good" by the senior loadmaster.

75 tons of aircraft descend to five feet. The seconds are like hours. Time drags unbearably as the plane hurtles along above the snow. A sudden whoosh, and the wait is over as the main chutes whip off the ramp and fill the air. It's a matter of one, two, three before the load slides along the rollers and sails out the door.



9,100 kg lighter, the Herc gathers speed and height. Below, the pallet has come to a stop, and the *Twin Otter* begins to roll and bob toward it. This delivery will keep airborne a small fleet of *Hueys, Chinooks* and *Otters* covering this area as part of Operation Morning Light, and needless to say, the residents of Fort Reliance will have something to talk about for the rest of the winter.

Below. Tense moments during Flight 6840. Still carrying its cargo, *Hercules* climbs to clear the ridge at Ft. Reliance, seconds after its wheels cut through the snow on Great Slave Lake during an unsuccessful LAPES drop. Photo was snapped by Dan Petrunik of the Ft. Reliance weather station. (ISC 78-1047)

On board the aircraft the crew relaxes. They've completed a tough job with consummate skill, exhibiting all the confidence of a professional team; no raised voices or pointing fingers, just calm, collected concentration at even the most critical moments.

With the task at hand over, the aircraft turns for home and everybody begins watching the snow below for wildlife.

Back in Edmonton, a 15,000 kg bulldozer sits securely anchored to a steel pallet, ready for the trip north. Today, at last light, this same crew will drop it out of the sky at Cosmos Lake — affectionately known at 435 Squadron as LAPES Lake. After all, in a week the squadron has dropped almost a quarter million kilograms of fuel and equipment at Fort Reliance and the Cosmos Lake base camp site.

But for now, there are caribou tracks below, and somebody has just spotted a wolf prowling through what has to be the most spectacular scenery in the world. Like any other job, a LAPES flight does have its perks.

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IN THE MATTER OF A CLAIM FOR COMPENSATION PRESENTED BY CANADA TO THE SOVIET UNION FOR DAMAGES INCURRED AS A RESULT OF THE INTRUSION ON CANADIAN TERRITORY ON JANUARY 24, 1978 OF THE COSMOS 954 SATELLITE LAUNCHED BY THE SOVIET UNION

AFFIDAVIT OF GEORGE ARTICHUK

I, GEORGE ARTICHUK, of the City of Ottawa, of the Province of Ontario, public servant, MAKE OATH AND SAY AS FOLLOWS:

1. I am employed in the position of Administrative Officer in the Department of Energy, Mines and Resources, Geological Survey of Canada, Resource Geophysics and Geochemistry Division (hereinafter referred to as the "Department") of the Government of Canada and as such I have knowledge of the matters hereinafter deposed.

2. In that position my regular duties include: being aware of expenditures incurred by the Department; being shown the invoices and other business records which document the amounts owed for services and materials rendered to the Department; being responsible for the necessary steps to determine if these invoices and business records accurately reflect the amounts owed for services and materials rendered to the Department; being certain that payments are made to the persons and the companies who have submitted the invoices and other business records for these services and materials rendered to the Department; and being responsible for the administration of the salary expenditures to the employees of the Department.

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3. Between January 24, 1978 and April 20, 1978 the Department was actively involved in the search and recovery operation for the debris from the Cosmos 954 Satellite.

I am informed by Dr. Keith A. Richardson, Head, Resource Radioactivity Subdivision, and I verily believe that:

The Geological Survey of Canada (GSC) has been active in research and development of instrumentation and techniques for high sensitivity airborne gamma-ray spectrometry surveying since 1968.

GSC involvement in Operation Morning Light was primarily in the airborne gamma-ray spectrometry search operations to locate radioactive satellite debris. These operations included both the fixed wing (CC130 Hercules) systematic surveys of the satellite track, and the helicopter (CH135) surveys to determine the distribution of radioactivity from the dispersed reactor core material, and to locate and mark for recovery pieces of debris that were found by the systematic surveys.

GSC experts were also sent to the location on the Thelon River near Warden's Grove to assist with ice drilling and probing to determine if the reactor core was attached to a large piece of satellite debris embedded in the ice there.

For the systematic airborne surveys with fixed wing aircraft, GSC provided a high sensitivity airborne gamma-ray spectrometer system, assisted in installing and interfacing the system with DND aircraft in Edmonton, modified the data acquisition computer programs and calibrated the system for detecting man-made radiation, operated the system on satellite search missions and performed electronics maintenance on the spectrometer system. A data analysis computer system was set up by GSC

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at CFB Edmonton, and GSC personnel carried out computer analysis of radiation and navigation data to locate sources of man-made radiation, reported the results daily to the Scientific Information Coordinator, and participated in meetings of the Hit Analysis Committee and Mission Planning Group.

For the helicopter operations, GSC prepared specifications for contracts for leasing 3 spectrometer systems and operating personnel from Canadian geophysical companies, and supervised the contract operations out of Yellowknife and the Warden's Grove camp. Computer programs were developed to analyse helicopter spectrometer data using the University of Alberta Computer Centre. GSC participated in planning of the helicopter operations, analysed the spectrometer data and prepared maps and reports on the results of the helicopter surveys.

4. The total amount spent by the Department to April 20, 1978 inclusive in the search and recovery operation was $254,564.14 dollars. These expenditures were incurred for the following goods and services. (See Annex I to Annex VIII attached).

5. The accounts, vouchers, receipts and other records relating to these expenses are in my control at the City of Ottawa.

SWORN BEFORE ME IN THE CITY OF)
OTTAWA, IN THE REGIONAL)
MUNICIPALITY OF OTTAWA-)
CARLETON THIS 23 DAY OF)
AUGUST, A.D. 1978)

[signature]
A Commissioner, etc. for the Province of Ontario

[signature]
George Artichuk

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DEPARTMENT OF ENERGY, MINES AND RESOURCES

GEOLOGICAL SURVEY OF CANADA

OPERATION MORNING LIGHT

RECAP - EXPENDITURES TO APRIL 20, 1978

ITEM	TOTAL COST	INCREMENTAL COST	
Personnel - Salaries	$41,307.66		
- Overtime	28,766.23	$28,766.23	Annex VIII
Travel	27,044.84	27,044.84	Annex I
Material Rental	72,000.00	72,000.00	Annex V
Material Consumed	7,647.49	7,647.49	Annex II, III, VI
Material Replacement	44,530.80	44,530.80	Annex VII
Contracts	74,574.78	74,574.78	Annex IV
	$295,871.80	$254,564.14	

April 21, 1978

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ANNEX I

TRAVEL (Ottawa-Edmonton, Yellowknife, Pinawa and return as required.

The total travel cost incurred by G.S.C. in connection with Operation Morning Light for the period January 24 - April 20, 1978 is $27,044.84, a figure supported by travel expense accounts and CTS airfare charges submitted for the period.

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Cosmos 954

Additional travel charges - direct billings

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Avis Rentals	Car rental GSC staff	14/4/78	$625.00
Avis Rentals	Car rental GSC staff	18/4/78	291.62
Avis Rentals	Car rental GSC staff	18/4/78	640.00
Avis Rentals	Car rental GSC staff	18/4/78	262.50
	TOTALS		$1,819.12

ANNEX II

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Cosmos 954

TRANSPORTATION OF PARCELS, ETC.

NAME OF SUPPLIER	SERVICE SUPPLIED	DATE OF PAYMENT	AMOUNT
Air Canada Express	Parcel of supplies	20/4/78	$12.00

ANNEX III

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Cosmos 954

TRANSPORTATION OF PARCELS, ETC.

NAME OF SUPPLIER	SERVICE SUPPLIED	DATE OF PAYMENT	AMOUNT
Air Canada Express	Parcel of supplies	20/4/78	$12.00

ANNEX III

Document disclosed under the *Access to Information Act* -
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COSMOS 954

PROFESSIONAL & SPECIAL SERVICES

NAME OF SUPPLIER	SERVICE SUPPLIED	DATE OF PAYMENT	AMOUNT
Scintrex Limited	Mobilization of two sets of Gamma-ray Spectrometer Equipment complete with operators, etc.	20/3/78	$3,427.20
McPhar Instrument Corp.	Mobilization, Rental of 1 set Gamma-ray Spectrometer for 1 week, two operators for one week	13/3/78	16,486.00
	Supplies for equipment	13/3/78	3,339.50
	Rental of equipment 2nd week operators, expenses	13/3/78	11,340.05
	Rental second set of equipment and mobilization	23/3/78	8,840.00
	Shipping charges - recorder	13/3/78	12.50
	Rental of equipment 3rd week, 2 sets, shipping charges, travel costs operators, operators expenses 3rd week	23/3/78	14,062.53
	Rental of equipment 4th week, 2 sets, operators living and labour expenses, Ground software program	28/3/78	17,067.00
		Totals	74,574.58

ANNEX IV

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COSMOS 954

RENTALS

NAME OF SUPPLIER	SERVICE SUPPLIED	DATE OF PAYMENT	AMOUNT
Geological Survey of Canada	Rental of Spectrometers 25 January - 31 March (9 weeks @ $8,000 per week)		$72,000.00

ANNEX V

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COSMOS 954

MATERIALS AND SUPPLIES

NAME OF SUPPLIER	SERVICE SUPPLIED	DATE OF PAYMENT	AMOUNT
Tektronix	Paper for equipment	4/4/78	$237.60
Graphic Controls	Paper for equipment	15/3/78	10.97
Graphic Controls	Paper for equipment	10/4/78	167.09
Keswell Equipment	Ice auger, extensions, blades, pins, bolts, nuts and washers	1/3/78	464.70
Canada Map Office	Maps	4/4/78	192.50
Data General	Service charges on equipment	28/3/78	225.00
Canada Map Office	Maps	28/3/78	207.00
Terra Surveys	Photomosaics	16/3/78	750.00
Houston Instruments	Chart Paper	23/3/78	102.11
Amersham Corp.	Cesium Sources	20/3/78	1,142.40
Canada Map Office	Maps	16/3/78	375.00
I.B.M.	Tape	20/2/78	1,730.00
Exploranium	Pens	4/4/78	120.00
Tektronix	Service Charges	5/4/78	82.50
Canada Map Office	Maps	6/4/78	4.50
		Totals	$5,816.37

ANNEX VI

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COSMOS 954

EQUIPMENT

NAME OF SUPPLIER	SERVICES SUPPLIED	DATE OF PAYMENT	AMOUNT
A. Crawford	Harshaw Scintillation Detectors	4/4/78	$18,656.00
Carrol Electronics	Digi Data Tape Transport with Midi Dek Controller	31/3/78	6,031.50
Carrol Electronics	Digi Data Tape Transport with Midi Dek Controller	31/3/78	6,031.50
Data General Limited		29/3/78	13,811.80
		Totals	44,530.80

ANNEX VII

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COSMOS 954

PERSONNEL COSTS - OVERTIME

NAME		HOURS WORKED		AMOUNT
BLANCHARD,	Y.B.	511.75		$4,306.02
BOUCHER,	D.M.	208.54		1,428.55
BRISTOW,	Q.	358.50		5,807.70
BURNS,	R.A.	88.75		792.00
CAMERON,	G.W.	232.75		2,403.15
DARNLEY,	A.G.	82.50		1,582.35
GRASTY,	R.L.	63.75		1,052.28
HOLMAN,	P.B.	301.75		3,240.36
HUNTER,	J.A.M.	15.00		224.00
HYATT	W.G.	381.27		2,491.15
PARKER,	J.	239.35		2,245.10
RICHARDSON,	K.A.	183.75		3,193.57
			Total	$28,766.23

ANNEX VIII

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IN THE MATTER OF A CLAIM FOR COMPENSATION PRESENTED BY CANADA TO THE SOVIET UNION FOR DAMAGES INCURRED AS A RESULT OF THE INTRUSION ON CANADIAN TERRITORY ON JANUARY 24, 1978 OF THE COSMOS 954 SATELLITE LAUNCHED BY THE SOVIET UNION

AFFIDAVIT OF RICHARD STEWART JENNINGS

I, LIEUTENANT-COLONEL RICHARD STEWART JENNINGS, of the City of Ottawa, in the Province of Ontario, Officer, Canadian Forces, MAKE OATH AND SAY AS FOLLOWS:

1. I am employed in the Directorate of Financial Services of the Department of National Defence (hereinafter referred to as the "Department") of the Government of Canada, and as such I have knowledge of the matters hereinafter disposed.

2. In that position I am responsible for the administration of Financial arrangements which lead to the eventual recovery of departmental costs for the provision of DND services in support of agencies external to the Department. This involves being aware of all expenditures for: salaries of members of the Canadian Forces both Regular Service and Reserves, and employees of the Department; rations and quarters, temporary duty expenses; fees paid to Non-DND Agencies; repairing, restoring and rewarehousing equipment; aircraft operating costs; materiels considered lost and destroyed; vehicle operating costs; transportation of personnel and freight on regular scheduled flights; rental of buildings and facilities; and miscellaneous costs.

3. Between January 24, 1978, and April 20, 1978, the Department was actively involved in the search and recovery operation for the debris from the Cosmos 954 Satellite. I am informed by Captain(N) Michael Barrow, former Director of Operations Centre, National Defence Headquarters, Ottawa, Canada, and I verily believe it to be true, that this Department was tasked to participate and assist in the search for and recovery of the Satellite debris, under the code name Operation Morning Light. The operation centered itself in the Yellowknife and Great Slave areas of the Northwest Territories of Canada.

4. Captain Barrow has also informed me, and I verily believe it to be true, that during its involvement in the search and recovery operation, this

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Department provided the aircraft, personnel, vehicles and other military equipment referred to in the attached appendices to search directly or to assist other Government of Canada Departments in the search and recovery operations.

5. I am informed by various military financial sources, and verily believe it to be true, that the total amount spent by the Department of National Defence to April 20, 1978, inclusive, in the search and recovery operation was $11,223,549.32. These expenditures are reflected on pages 1 to 19 of Annex A attached hereto as appendices.

6. The accounts, vouchers, receipts and other records relating to these expenses are at my disposal at the City of Ottawa.

SWORN before me at the City of Ottawa, in the Regional Municipality of Ottawa-Carleton, this 18th day of September, A.D. 1978.

Richard Stewart [signature] LCOL

Douglas Brian Murphy
Lieutenant-Colonel
Notary Public in and for the Province of Ontario for the Government of Canada

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ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

OPERATION MORNINGLIGHT
SUMMARY OF COSTS - EPARTMENT OF NATIONAL DEFENCE
AS AT 20 APRIL, 1978

DNDP 55 Serial	Item		Total Cost		Incremental Cost
1	Military Personnel (Appendices 1&2)				
	FY 77/78	$1,224,459.87			
	FY 78/79	348,218.39			
	Total	$1,572,678.26	$1,572,678.26		$ 8,685.00
2	Reserve Force Personnel		Ø		Ø
3	Rations and Quarters (Appendix 3)		48,468.01		48,468.01
4	Temporary Duty		520,853.34		520,853.34
5	Civilian Personnel (Appendices 4&5)				
	FY 77/78	$ 30,640.21			
	FY 78/79	8,341.31			
	Total	$ 38,981.52	38,981.52		Ø
6	Casual Labour		Ø		Ø
7	Civilian Overtime (Appendices 6&7)				
	FY 77/78	$ 17,267.50		$ 17,267.50	
	FY 78/79	4,915.71		4,915.71	
	Total	$ 22,183.21	22,183.21	$ 22,183.21	22,183.21
8	Fees Paid to Non-DND Agencies (Appendix 8)		220,342.66		220,342.66
9	Repairing, Restoring, Rewarehousing		57.00		57.00
10	Aircraft Cost (Appendix 9)				
	FY 77/78	$5,480,511.28		$2,039,495.92	
	FY 78/79	467,490.30		176,756.60	
	Crew Cost	1,427,914.95		Ø	
	Total	$7,375,916.53	7,375,916.53	$2,216,252.52	$2,216,252.52
11	Materials Consumed, Lost, Destroyed (Appendix 10)		290,360.43		290,360.43

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PAGE 2 TO ANNEX A
TO: AFFIDAVIT OF RICHARD STEWARD JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

DNDP 55 Serial	Item			Total Cost		Incremental Cost	
12	Vehicles (Appendix 11)						
	FY 77/78	$ 56,665.54			$ 14,479.12		
	FY 78/79	15,472.66			4,111.17		
	Total	$ 72,138.20	$	72,138.20	18,590.29	$	18,590.29
13	Transportation of Personnel and Freight on Regular Scheduled Flights (Appendix 12)			17,253.31			Ø
14	Rental for Buildings and Facilities			20,302.75			20,302.75
15	Caretaker Wages for Serial 14			Ø			Ø
16	Miscellaneous Costs (Appendix 13)			3,691.43			3,691.43
	Sub Total			$10,203,226.65			$3,369,786.64
	10% DND Administration			1,020,322.67			336,978.66
	Total			$11,223,549.32			$3,706,765.30

Prepared by D Cost S
Dated: 14 Aug 78

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APPENDIX 1 TO
ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

OPERATION MORNINGLIGHT
REGULAR FORCE PERSONNEL COSTS FY 77/78

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rank	No. of Mandays 77/78	No. of Manhours 77/78	Annual Salary FY 77/78	Annual Mandays/Hrs	77/78 Cost M/Days	77/78 Cost M/Hours	Total Reg. Force Costs 77/78
BGen	1.58	0	$40,278	189/1510	$ 336.72	$ 0	$ 336.72
Col	74.26	0	39,017	189/1510	15,330.17	0	15,330.17
LCol	286.77	5.14	35,276	189/1510	53,524.33	120.08	53,644.41
Maj	279.70	1.58	31,212	189/1510	46,190.46	32.66	46,223.12
Capt	831.91	4.35	25,147	189/1510	110,688.05	72.36	110,760.41
Lt	414.79	5.13	16,309	189/1510	35,792.65	55.46	35,848.11
2nd Lt	15.00	0	13,725	189/1510	1,089.29	0	1,089.29
CWO	60.83	0	25,520	189/1510	8,213.66	0	8,213.66
MWO	82.16	3.16	22,838	189/1510	9,927.88	47.79	9,975.67
WO	106.68	.39	20,382	189/1510	11,504.51	5.26	11,509.77
Sgt	791.60	6.71	18,154	189/1510	76,035.48	80.67	76,116.15
MCpl	1,405.42	5.95	16,851	189/1510	125,305.46	66.40	125,371.86
Cpl	489.77	3.16	16,009	189/1510	41,485.33	33.50	41,518.83
C-P	2,595.94	3.95	12,268	189/1510	168,502.60	32.09	168,534.69
Pte	511.88	3.16	9,488	189/1510	25,696.92	19.85	25,716.77
Totals	7,948.29	42.68			$729,623.51	$566.12	$730,189.63

ADD: Base Support

FY 77/78 $11,582.17 x 7,948.29 mandays ÷ 189 Ann Mandays =	$487,081.72	
11,582.17 x 42.68 Manhours ÷ 1510 Ann Manhours =	327.37	
Total Base Support Costs	487,409.09	
Add Field Ops Allowance	6,861.15	494,270.24
Total Reg. Force Personnel Costs & Base Support Costs (77/78)		$1,224,459.87

METHODOLOGY: Col(2) x Col(4) ÷ Col(5) = Col(6)
Col(3) x Col(4) ÷ Col(5) = Col(7)
Col(8)

Prepared by D Cost S
Dated: 14 Aug 78

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APPENDIX 2 TO
ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

OPERATION MORNINGLIGHT
REGULAR FORCE PERSONNEL COSTS FY 78/79

(1) Rank	(2) No. of Mandays 78/79	(3) No. of Manhours 78/79	(4) Annual Salary FY 78/79	(5) Annual Mandays/Hrs	(6) 78/79 Cost M/Days	(7) 78/79 Cost M/Hours	(8) Total Reg. Force Costs 78/79
BGen	.42	0	$42,878	189/1510	$ 95.28	$ 0	$ 95.28
Col	19.74	0	41,350	189/1510	4,318.78	0	4,318.78
LCol	76.23	1.36	37,607	189/1510	15,168.16	33.87	15,202.03
Maj	74.30	.42	33,295	189/1510	13,088.99	9.26	13,098.25
Capt	221.09	1.15	26,892	189/1510	31,457.95	20.48	31,478.43
Lt	110.21	1.37	17,373	189/1510	10,130.57	15.76	10,146.33
2nd Lt	4.00	0	13,961	189/1510	295.47	0	295.47
CWO	16.17	0	27,246	189/1510	2,331.05	0	2,331.05
MWO	21.84	.84	24,367	189/1510	2,815.74	13.55	2,829.29
WO	28.32	.11	21,723	189/1510	3,255.00	1.58	3,256.58
Sgt	210.40	1.79	19,348	189/1510	21,538.73	22.94	21,561.67
MCpl	373.58	2.75	17,942	189/1510	35,464.40	32.68	35,497.08
Cpl	130.23	.84	17,004	189/1510	11,716.57	9.46	11,726.03
C-P	690.06	1.05	12,955	189/1510	47,300.14	9.01	47,309.15
Pte	136.12	.84	10,025	189/1510	7,220.12	5.58	7,225.70
Totals	2,112.71	12.52			$206,196.95	$174.17	$206,371.12

ADD: Base Support

FY 78/79 $12,517.01 x 2,112.71 Mandays ÷ 189 Ann Mandays =	$139,919.64	
12,517.01 x 12.52 Manhours ÷ 1510 Ann Manhours =	103.78	
Total Base Support Costs	$140,023.42	
Add Field Ops Allowance	1,823.85	141,847.27
Total Reg. Force Personnel Costs & Base Support Costs (78/79)		$348,218.39

Total Military Personnel Costs	FY 77/78	$1,224,459.87
	FY 78/79	348,218.39
		$1,572,678.26

Prepared by D Cost S
Dated: 14 Aug 78

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APPENDIX 3 TO
ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

OPERATION MORNINGLIGHT
RATIONS AND QUARTERS

RATIONS:

CFB Edmonton -	Rations	$15,947.30	
	Cosmos Lake Rations	13,774.74	
	Flight Feeding	14,184.22	
		$43,906.26	$43,906.26
CFB Calgary			335.37
CFB Petawawa			99.40
CFB Summerside - Flight Meals			490.42
CFB Ottawa - Meals			63.30
Communications Command			58.18
Northern Region Headquarters (Local Purchases for Cosmos Lake)			1,794.38
Defence Research Board			49.10
Total Rations			$46,796.41

QUARTERS:

CFB Edmonton	$ 1,593.89
CFB Calgary	19.17
CFB Petawawa	35.21
Communications Command	12.50
Defence Research Board	10.83
Total Quarters	$ 1,671.60

Total Rations and Quarters $48,468.01

Prepared by D Cost S
Dated: 14 Aug 78

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APPENDIX 4 TO
ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

OPERATION MORNINGLIGHT
CIVILIAN PERSONNEL COSTS 77/78

Class	Annual Pay FY 77/78	Prem Pay	Govt. Cont.	Other Bene.	Total Annual Pay & Allow.	No. of Hrs/Days	Annual Hrs/Days	Total Cost
DS 3	$21,351	0	$2,775.63	138	$24,264.63	50.6 days	216.5	$ 5,671.09
DS 4	28,832	0	3,748.16	138	32,718.16	30 days	216.5	4,533.69
DS 5	33,869	0	4,402.97	138	38,409.97	10.3 days	216.5	1,827.36
CM 3	12,319	0	1,601.47	138	14,058.47	8.7 days	216.5	564.94
EIM 10	15,214	180	2,001.22	138	17,533.22	44.2 hrs	1852	418.45
MDO 4	11,433	180	1,509.69	138	13,260.69	347.6 hrs	1852	2,488.88
MDO 5	11,823	180	1,560.39	138	13,701.39	198.5 hrs	1852	1,468.53
MDO 6	11,997	180	1,583.01	138	13,898.01	6.3 hrs	1852	47.28
BUS 2	9,255	180	1,226.55	138	10,799.55	134.3 hrs	1852	783.14
WOW 8	13,885	180	1,828.45	138	16,031.45	5 days	231.5	346.25
WOW 9	14,147	180	1,862.51	138	16,327.51	81.4 hrs/5 days	1852/231.5	1,070.28
ELE 2	10,302	180	1,362.66	138	11,982.66	76.6 hrs	1852	495.61
ELE 3	10,957	180	1,447.81	138	12,722.81	104.6 hrs	1852	718.58
ELE 5	12,951	180	1,683.63	138	14,952.63	30.8 hrs	1852	248.67
STS 2	9,693	180	1,283.49	138	11,294.49	2.4 hrs	1852	14.64
STS 4	12,503	180	1,648.79	138	14,469.79	1.2 hrs	1852	9.38
STS 5	13,326	180	1,755.78	138	15,399.78	4 hrs	1852	33.26
STS 7	15,336	180	2,017.08	138	17,671.08	3.2 hrs	1852	30.53
PIP 9	14,839	180	1,929.07	138	17,086.07	41.9 hrs	1852	386.56
PRW 6	13,429	180	1,745.77	138	15,492.77	58.5 hrs	1852	489.38
VHE 9	13,943	180	1,812.59	138	16,073.59	27.7 hrs	1852	240.41
VHE 10	15,584	180	2,025.92	138	17,927.92	1.2 hrs	1852	11.62
								$21,898.53

ADD: Base Support ($11,582.17 - 1/3) x 99.6 Mandays ÷ 216.5 Ann Mandays = $3,552.22
($11,582.17 - 1/3) x 10 Mandays ÷ 231.5 Ann Mandays = 333.54
($11,582.17 - 1/3) x 1,164.7 Manhours ÷ 1852 Ann Manhours = $4,855.92
Total Base Support Costs 77/78 — 8,741.68

Civilian Personnel Costs 77/78 — $30,640.21

Prepared by D Cost S
Dated: 14 Aug 78

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APPENDIX 5 TO
ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

OPERATION MORNINGLIGHT
CIVILIAN PERSONNEL COSTS 78/79

Class	Annual Pay FY 78/79	Prem. Pay	Govt. Cont.	Other Bene.	Total Annual Pay & Allow.		No. of Hrs/Days		Annual Hrs/Days		Total Cost
DS 3	$22,298	0	$2,898.74	159	$25,355.74	x	13.4 days	÷	216.5	=	$1,569.36
DS 4	30,111	0	3,914.43	159	34,184.43		8 days		216.5		1,263.17
DS 5	35,371	0	4,598.23	159	40,128.23		2.7 days		216.5		500.44
CM 3	13,111	0	1,704.43	159	14,974.43		2.3 days		216.5		159.08
EIM 10	16,901	189	2,221.70	159	19,470.70		11.8 hrs		1852		124.06
MDO 4	11,878	189	1,568.71	159	13,794.71		92.4 hrs		1852		688.25
MDO 5	12,299	189	1,623.44	159	14,270.44		52.8 hrs		1852		406.85
MDO 6	12,464	189	1,644.89	159	14,456.89		1.7 hrs		1852		13.27
BUS 2	10,289	189	1,362.14	159	11,999.14		35.7 hrs		1852		231.30
WOW 8	-	-	-	-	-		-		1852		-
WOW 9	15,379	189	2,023.84	159	17,750.84		21.6 hrs		1852		207.03
ELE 2	10,883	189	1,439.36	159	12,670.36		20.4 hrs		1852		139.57
ELE 3	11,553	189	1,526.46	159	13,427.46		27.9 hrs		1852		202.28
ELE 5	13,649	189	1,798.94	159	15,795.94		8.2 hrs		1852		69.94
STS 2	10,823	189	1,431.56	159	12,602.56		.6 hrs		1852		4.08
STS 4	14,021	189	1,847.30	159	16,216.30		.3 hrs		1852		2.63
STS 5	14,822	189	1,951.43	159	17,121.43		1. hrs		1852		9.24
STS 7	17,303	189	2,273.96	159	19,924.96		.8 hrs		1852		8.61
PIP 9	16,773	189	2,205.06	159	19,326.06		11.1 hrs		1852		115.83
PRW 6	14,569	189	1,918.54	159	16,835.54		15.5 hrs		1852		140.90
VHE 9	14,491	189	1,908.40	159	16,747.40		7.3 hrs		1852		66.01
VHE 10	16,219	189	2,133.04	159	18,700.04		.3 hrs		1852		3.03
											$5,924.93

ADD: Base Support (12,517.01 - 1/3) x 26.5 Mandays ÷ 216.5 Ann Mandays = $1,021.40
(12,517.01 - 1/3) x 309.6 Manhours ÷ 1852 Ann Manhours = 1,394.98
Total Base Support Costs 78/79 2,416.38

Civilian Personnel Costs 78/79 $ 8,341.31
Total Civilian Personnel Costs 77/78 - 78/79 $38,981.52

Prepared by D Cost S
Dated: 14 Aug 78

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APPENDIX 6 TO
ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

OPERATION MORNINGLIGHT
CIVILIAN OVERTIME COSTS 77/78

Class	Annual Pay 77/78	Prem Pay	Govt. Cont.	Other Bene.	Total Ann. Pay & Allow	No. of Hrs O/T	Annual Man Hrs	Total Cost
DS 3	$21,351	$ 0	$2,775.63	$138	$24,264.63	355.5	1624	$ 7,967.43
DS 4	28,832	0	3,748.16	138	32,718.16	113.2	1624	3,420.90
DS 5	33,869	0	4,402.97	138	38,409.97	32.4	1624	1,149.46
ELE 2	10,302	180	1,362.66	138	11,982.66	82.2	1852	797.76
ELE 3	10,957	180	1,447.81	138	12,722.81	11.1	1852	114.37
ELE 5	12,951	180	1,683.63	138	14,952.63	21.7	1852	262.80
BUS 2	9,255	180	1,226.55	138	10,799.55	74.7	1852	653.40
STS 4	12,503	180	1,648.79	138	14,469.79	3.6	1852	42.20
MDO 4	11,433	180	1,509.69	138	13,260.69	.6	1852	6.44
MDO 5	11,823	180	1,560.39	138	13,701.39	-	1852	-
PIP 9	14,839	180	1,929.07	138	17,086.07	15.4	1852	213.11
VHE 9	13,943	180	1,812.59	138	16,073.59	2.4	1852	31.24
VHE 10	15,584	180	2,025.92	138	17,927.92	.8	1852	11.62
WOW 8	13,885	180	1,828.45	138	16,031.45	7.1	1852	92.19
WOW 9	14,147	180	1,862.51	138	16,327.51	11.3	1852	149.43
MAN 6	14,212	180	1,870.96	138	16,400.96	5.5	1852	73.06
HP 4	16,331	180	2,146.43	138	18,795.43	53.3	1624	925.30
FOS 2	7,350	180	978.90	138	8,646.90	110.4	1852	773.18
FOS 3	8,704	180	1,154.92	138	10,176.92	19.5	1852	160.73
CR 2	9,209	0	1,197.17	138	10,544.17	17.4	1624	169.46
CR 3	11,164	0	1,451.32	138	12,753.32	15.0	1624	176.69
STN 2	9,949	0	1,293.37	138	11,380.37	7.3	1624	76.73
						960.40 hrs		
					Civilian Overtime Costs 77/78			$17,267.50

Prepared by D Cost S
Dated: 14 Aug 78

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APPENDIX 7 10
ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

OPERATION MORNINGLIGHT
CIVILIAN OVERTIME COSTS 78/79

Class	Annual Pay 78/79	Prem Pay	Govt Cont	Other Bene.	Total Ann. Pay & Allow	No. of Hrs O/T	Annual Man Hrs	Total Cost
DS 3	$22,298	$ 0	$2,898.74	$159	$25,355.74	94.5	1624	$ 2,213.16
DS 4	30,111	0	3,914.43	159	34,184.43	30.1	1624	950.39
DS 5	35,371	0	4,598.23	159	40,128.23	8.6	1624	318.75
ELE 2	10,883	189	1,439.36	159	12,670.36	21.8	1852	223.72
ELE 3	11,553	189	1,526.46	159	13,427.46	2.9	1852	31.53
ELE 5	13,649	189	1,798.94	159	15,795.94	5.8	1852	74.20
BUS 2	10,289	189	1,362.14	159	11,999.14	19.8	1852	192.43
STS 4	14,021	189	1,847.30	159	16,216.30	.9	1852	11.82
MDO 4	11,878	189	1,568.71	159	13,794.71	.15	1852	1.68
MDO 5	12,299	189	1,623.44	159	14,270.44	6.5	1852	75.13
PIP 9	16,773	189	2,205.06	159	19,326.06	4.1	1852	64.18
VHE 9	14,491	189	1,908.40	159	16,747.40	.6	1852	8.14
VHE 10	16,219	189	2,133.04	159	18,700.04	.2	1852	3.03
WOW 8	14,471	189	1,905.80	159	16,724.80	1.9	1852	25.74
WOW 9	15,379	189	2,023.84	159	17,750.84	3.0	1852	43.13
MAN 6	14,789	189	1,947.14	159	17,084.14	1.5	1852	20.76
HP 4	17,379	189	2,283.84	159	20,010.84	14.2	1624	262.46
FOS 2	8,206	189	1,091.35	159	9,645.35	29.3	1852	228.89
FOS 3	9,731	189	1,289.60	159	11,368.60	5.2	1852	44.88
CR 2	9,738	0	1,265.94	159	11,162.94	4.6	1624	47.43
CR 3	11,832	0	1,538.16	159	13,529.16	4.0	1624	49.98
STN 2	10,595	0	1,377.35	159	12,131.35	1.9	1624	21.29
						261.55		

Civilian Overtime Costs 78/79 $ 4,915.71

Total Civilian Overtime Costs $22,183.21

Prepared by D Cost S
Dated: 14 Aug 78

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APPENDIX 8 TO
ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART
JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

OPERATION MORNINGLIGHT
CHARGES AND/OR FEES PAID TO NON/DND AGENCIES

Communication Facilities:		
Lease of Microwave System	$ 39,500.00	
Access Lines	34,092.13	
Pocket Pagers	1,661.59	
Total	$ 75,253.72	$ 75,253.72
Lease of an Inertial Navigation System		$ 6,600.00
Lease of Mobile Support Equipment:		
Vehicles	$ 37,330.28	
Bulldozers	6,902.00	
Total	$ 44,232.28	$ 44,232.28
Vehicle Repairs		$ 1,824.24
Lease and Installation of Heating		$ 23,893.32
Lease of Chemical Toilets		231.43
Lease of a Skidoo		245.00
Provide and Install Wash Car at Cosmos Lake		37,500.00
Freight Services		1,450.75
Cleaning Services		1,032.75
Consulting Services		1,520.44
Photographic Services		8,729.87
Garbage Collection		3,026.57
Xerox Service		156.00
Electrical Contractor		2,269.58
Local Purchase and Petty Cash		12,376.71
Total		$220,342.66

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APPENDIX 9 TO
ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

OPERATION MORNINGLIGHT AIRCRAFT COSTS

Type of Aircraft	(1) Total Hrs Flown	(2) Total Hrs Flown 77/78	(3) Total Hrs Flown 78/79	(4) Total Aircraft Operating Costs 77/78 $	(5) Total Aircraft Operating Costs 78/79 $	(6) Incremental Aircraft Operating Cost 77/78 $	(7) Incremental Aircraft Operating Cost 78/79 $	(8) Total Aircraft Operating Cost (4+5) $	(9) Total Crew Cost $	(10) Total Aircraft Cost (8+9) $	(11) Incremental Cost (6+7) $
CC 130 Herc	1898.0	1809.0	89.0	2,785,172.58	138,484.00	1,116,822.33	62,478.00	2,923,656.58	638,578.00	3,562,234.58	1,179,300.33
CC 137 Boeing	8.7	3.7		9,706.21		4,581.67		9,706.21	1,675.00	11,381.21	4,581.67
CH 138 Twin Otter	309.8	301.3	8.5	167,468.57	4,224.50	36,279.53	1,139.00	171,693.07	57,416.31	229,109.38	37,418.53
CH 135 Twin Huey	1539.8	1306.1	233.7	923,386.58	174,573.90	329,111.08	64,734.90	1,097,960.48	320,037.00	1,417,997.48	393,845.98
CH 147 Chinook	499.0	441.1	57.9	639,250.94	110,241.60	145,532.12	33,871.50	749,492.54	177,377.87	926,870.41	179,403.62
CP 107 Argus	157.8	157.8		504,936.33		226,343.59		504,936.33	124,531.00	629,467.33	226,343.59
CC 115 Buffalo	135.9	135.9		251,656.90		112,585.00		251,656.90	47,727.27	296,384.17	112,585.00
CH 136 Kiowa	509.6	399.5	110.1	132,354.35	39,966.30	42,894.32	14,533.20	172,320.65	53,396.50	225,717.15	57,427.52
CC 109 Cosmo	13.2	13.2		17,175.31		4,708.97		17,175.31	4,122.98	21,298.29	4,708.97
CC 117 Falcon	11.5	11.5		15,374.12		7,991.81		15,374.12	3,757.94	19,132.06	7,991.81
CT 133 Silverstar	4.2	4.2		2,666.16		1,362.94		2,666.16	800.00	3,466.16	1,362.94
CF5/CF 116	13.6	13.6		31,363.23		11,282.56		31,363.23	1,495.08	32,858.31	11,282.56
Total Costs								5,948,001.58	1,427,914.95	7,375,916.53	2,216,252.52

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APPENDIX 10 TO
ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

OPERATION MORNINGLIGHT
MATERIALS LOST, CONSUMED OR DESTROYED

Item	
Materials Consumed - Air Command	$ 10,802.96
Materials Consumed - Mobile Command	3,924.10
Maps and Charts	19,207.50
Local Purchases	120,889.17
Construction Materials - 1 CEU	37,327.67
Materials Condemned	340.75
Materials Lost	13,109.27
Petroleum, Oil and Lubricants	10,320.95
Materials - Lapes Flights	65,980.96
Sub Total	$281,903.33
3% DSS Service Charge (except Local Purchases)	8,457.10
Total	$290,360.43

Prepared by D Cost S
Dated: 14 Aug 78

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PEN 11
ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy, Notary Public

OPERATION MORNINGLIGHT VEHICLE COSTS

ECC	Type	Total No. of Miles/KM/Hrs	77/78 Miles/KM/Hrs	78/79 Miles/KM/Hrs	Total Cost 77/78 $	Incremental Cost 77/78 $	Total Cost 78/79 $	Incremental Cost 78/79 $	Total Cost $	Incremental Cost $
103501	Forklift 6000 lbs	12.5 Hrs	9.88 Hrs	2.62 Hrs	75.98	21.59	10.57	1.99	86.55	23.58
103950	Forklift 10,000 lbs	44. Hrs	34.76 Hrs	9.24 Hrs	470.66	58.40	120.76	12.48	591.42	70.88
123101	5/4 Ton	801. KM	632.79 KM	168.21 KM	202.49	44.30	52.15	15.14	254.64	59.44
123103	5/4 Ton	1233. KM	974.07 KM	258.93 KM	321.44	68.18	103.57	33.66	425.01	101.84
123104	5/4 Ton	3197. KM	2525.63 KM	671.37 KM	883.97	176.79	187.98	53.71	1,071.95	230.50
123306	5/4 Ton	77.2 Mi	60.99 Mi	16.21 Mi	31.71	4.27	13.94	6.48	45.65	10.75
123327	5/4 Ton	48. KM	37.92 KM	10.08 KM	18.58	10.62	5.64	3.23	24.22	13.85
124108	5/4 Ton	10. KM	7.90 KM	2.10 KM	5.37	3.63	1.64	1.09	7.01	4.72
132213	Generator	539. Hrs	425.81 Hrs	113.19 Hrs	510.97	510.97	169.79	169.79	680.76	680.76
140101	S/C	271. Mi	214.09 Mi	56.91 Mi	47.10	19.27	12.52	3.98	59.62	23.25
140105	S/C	3089. Mi	2440.31 Mi	648.69 Mi	707.69	170.82	142.71	64.87	850.40	235.69
140110	Lt Duty	4. Mi	3.16 Mi	.84 Mi	2.02	.57	.51	.10	2.53	.67
140113	S/C	9799. Mi	7741.21 Mi	2057.79 Mi	2,322.36	619.30	576.18	164.62	2,898.54	783.92
140124	S/C	1862. Mi	1470.98 Mi	391.02 Mi	264.78	102.97	82.11	27.37	346.89	130.34
140126	S/W	13756. Mi	10867.24 Mi	2888.76 Mi	2,608.14	978.05	779.97	259.99	3,388.11	1,238.04
140131	½ Ton Pers Carrier	3534. Mi	2791.86 Mi	742.14 Mi	1,730.95	558.37	423.02	141.01	2,153.97	699.38
140205	Tracked Sled	893. Hrs	705.47 Hrs	187.53 Hrs	14,786.65	3,414.47	3,836.86	797.00	18,623.51	4,211.47
140316	Self Prop	84. Hrs	66.36 Hrs	17.64 Hrs	938.99	265.44	299.17	19.76	1,238.16	285.20
140530	Bus 16 Pax	2033. Mi	1606.07 Mi	426.93 Mi	819.10	273.03	157.96	55.50	977.06	328.53
140535	Bus 28 Pax	566. Mi	477.14 Mi	118.86 Mi	286.28	114.51	54.68	22.58	340.96	137.09
140540	Bus 40 Pax	640. Mi	506.60 Mi	134.40 Mi	328.64	131.46	106.18	43.01	434.82	174.47
140550	Bus 40 Pax	205. Mi	161.95 Mi	43.05 Mi	173.29	42.11	23.68	12.05	196.97	54.16
142101	1 Ton	161. Mi	127.19 Mi	33.81 Mi	50.88	10.18	11.83	4.06	62.71	14.24
142103	Panel	3218. Mi	2542.22 Mi	675.78 Mi	788.09	254.22	216.25	67.58	1,004.34	321.80
142106	1 Ton	305. Mi	240.95 Mi	64.05 Mi	86.74	21.69	24.34	8.33	111.08	30.02
142115	Ext Cab W/W	300. Mi	237.00 Mi	63.00 Mi	130.35	30.81	34.02	15.12	164.37	45.93
145115	3 Ton Stake	1636. Mi	1292.44 Mi	343.56 Mi	465.28	155.09	171.78	51.53	637.06	206.62
145116	3 Ton Stake	1802. Mi	1423.58 Mi	378.42 Mi	512.49	170.83	158.94	45.41	671.43	216.24
145119	3 Ton Stake	512. Mi	404.48 Mi	107.52 Mi	153.70	48.54	50.53	16.13	204.23	64.67
146114	1 Ton	5.5 Mi	4.35 Mi	1.15 Mi	1.57	.39	.44	.15	2.01	.54
148106	Tractor	838. Mi	662.02 Mi	175.98 Mi	463.41	238.33	137.26	59.83	600.67	298.16

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APPENDIX 11 TO
ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

ECC	Type	Total No. of Miles/KM/Hrs	77/78 Miles/KM/Hrs	78/79 Miles/KM/Hrs	Total Cost 77/78 $	Incremental Cost 77/78 $	Total Cost 78/79 $	Incremental Cost 78/79 $	Total Cost $	Incremental Cost $
149102	Tractor	1545. Mi	1220.60 Mi	324.40 Mi	549.27	305.15	165.44	90.83	714.71	395.98
149104	Tractor	934. Mi	737.86 Mi	196.14 Mi	605.05	398.44	180.45	119.65	785.50	518.09
158103	Trailer Included with ECC 149102	1545. Mi	1220.60 Mi	324.40 Mi	Ø	Ø	Ø	Ø	Ø	Ø
163123	Scoop	852. Hrs	673.08 Hrs	178.92 Hrs	14,397.18	3,688.48	3,961.29	1,171.93	18,358.47	4,860.41
167115	AUX Snow Blower	582. Hrs	459.78 Hrs	122.22 Hrs	10,924.37	1,567.85	3,198.50	551.21	14,122.87	2,119.06
									72,138.20	18,579.27

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APPENDIX 12 TO
ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

OPERATION MORNINGLIGHT
TRANSPORTATION COST OF PERSONNEL AND FREIGHT
TRAVELLING ON REGULAR SCHEDULED FLIGHTS

Statistics:

Total Passengers	145	
Total Passenger Miles	147,070	
Total Freight	18,568 lbs.	
Cost Per Passenger Per Nautical Mile	$ 0.074	
Cost Per Hundred Weight Per Nautical Mile	$ 0.0232	
Passenger Cost		
147,070 x $0.074		$ 10,883.18
Freight		
16,468 lbs - Ottawa/Edmonton 164.68 c.w.t. x 1580 nm x $0.0232	$6,036.51	
2,000 lbs - Edmonton/Winnipeg 20.0 c.w.t. x 640 nm x $0.0232	296.96	
100 lbs - Edmonton/Ottawa 1 c.w.t. x 1,580 nm x $0.0232	36.66	
Total Freight	$6,370.13	$ 6,370.13
Total Passengers and Freight		$ 17,253.31

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APPENDIX 13 TO
ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

OPERATION MORNINGLIGHT
MISCELLANEOUS COSTS

Medical Examinations	$ 1,514.18
Hotel Charges - Americans	2,177.25
Total	$ 3,691.43

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AN B
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

OPERATION MORNINGLIGHT
AIRCRAFT COSTS (ADJUSTED)

Type of Aircraft	(1) Total Hours Flown	(2) Total Hours Flown 77/78	(3) Total Hours Flown 78/79	(4) Aircraft Cost Per Flying Hr 77/78 $	(5) Aircraft Cost Per Flying Hr 78/79 $	(6) Total Aircraft Operating Cost 77/78 $	(7) Total Aircraft Operating Cost 78/79 $	(8) Total Aircraft Operating Cost $
CC 130 Hercules	1898.0	1809.0	89.0	899.47	1,000.00	1,627,141.23	89,000.00	1,716,141.23
CC 137 Boeing	3.7	3.7	Ø	3,852.10	Ø	14,252.77	Ø	14,252.77
CH 138 Twin Otter	309.8	301.3	8.5	265.72	294.00	80,061.44	2,499.00	82,560.44
CH 135 Twin Huey	1539.8	1306.1	233.7	494.24	528.00	645,526.86	123,393.60	768,920.46
CH 147 Chinook	499.0	441.1	57.9	1,027.61	1,470.00	453,278.77	85,113.00	538,391.77
CP 107 Argus	157.8	157.8	Ø	2,213.51	Ø	349,291.88	Ø	349,291.88
CC 115 Buffalo	135.9	135.9	Ø	1,399.22	Ø	190,154.00	Ø	190,154.00
CH 136 Kiowa	509.6	399.5	110.1	170.78	198.00	68,226.61	21,799.80	90,026.41
CC 109 Cosmopolitan	13.2	13.2	Ø	825.40	Ø	10,895.28	Ø	10,895.28
CC 117 Falcon	11.5	11.5	Ø	988.76	Ø	11,370.74	Ø	11,370.74
CT 133 Silverstar	4.2	4.2	Ø	389.18	Ø	1,634.56	Ø	1,634.56
CF5/CF116	13.6	13.6	Ø	1,718.18	Ø	23,367.25	Ø	23,367.25
Total Costs						3,475,201.39	321,805.40	3,797,006.79

Prepared by D Cost S
Dated: 14 Aug 78

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ANNEX C
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy
Notary Public

OPERATION MORNINGLIGHT
VEHICLE COSTS (ADJUSTED)

ECC	Type	Total No. of Miles/KM/Hrs		77/78 Miles/KM/Hrs		78/79 Miles/KM/Hrs		Total Cost Per Hour 77/78 $	Total Cost Per Hour 78/79 $	Total Cost 77/78 $	Total Cost 78/79 $	Total Cost $
103501	Forklift 6000 lbs	12.5	hrs	9.88	hrs	2.62	hrs	5.79	6.37	57.21	16.69	73.90
103950	Forklift 10000 lbs	4.4	hrs	34.76	hrs	9.24	hrs	11.22	10.66	390.01	98.50	488.51
123101	5/4 Ton	801	KM	632.79	KM	168.21	KM	.29	.25	183.51	42.05	225.56
123103	5/4 Ton	1233	KM	974.07	KM	258.93	KM	.30	.30	292.22	77.68	369.90
123104	5/4 Ton	3197	KM	2525	KM	671.37	KM	.32	.25	808.20	167.84	976.04
123306	5/4 Ton	77.2	Mi	60.99	Mi	16.21	Mi	.38	.70	29.34	42.69	72.03
123327	5/4 Ton	48	KM	37.92	KM	10.08	KM	.41	.47	15.55	4.74	20.29
124108	5/4 Ton	10	KM	7.90	KM	2.10	KM	.46	.52	3.63	1.09	4.72
132213	Generator	539	Hrs	425.81	Hrs	113.19	Hrs	1.20	1.50	510.97	169.79	680.76
140101	S/C	271	Mi	214.09	Mi	56.91	Mi	.18	.17	6.94	9.67	16.61
140105	S/C Ambulance	3089	Mi	2440.31	Mi	648.69	Mi	.25	.17	610.08	110.28	720.36
140110	Lt Duty	4	Mi	3.16	Mi	.84	Mi	.38	.37	1.20	.31	1.51
140113	S/C	9799	Mi	7741.21	Mi	2057.79	Mi	.24	.24	1,857.89	493.87	2,351.76
140124	S/C	1862	Mi	1470.98	Mi	391.02	Mi	.17	.18	250.07	70.38	320.45
140126	S/W	13756	Mi	10867.24	Mi	2888.76	Mi	.18	.21	1,956.10	606.64	2,562.74
140131	½ Ton Pers Carrier	3534	Mi	2791.86	Mi	742.14	Mi	.44	.38	1,228.42	282.01	1,510.43
140205	Tracked Sled	893	Hrs	705.47	Hrs	187.53	Hrs	20.82	20.30	14,687.88	3,806.86	18,494.74
140316	Self Prop.	84	Hrs	66.36	Hrs	17.64	Hrs	10.45	15.43	693.46	272.19	965.65
140530	Bus 16 Pax	2033	Mi	1606.07	Mi	426.93	Mi	.35	.28	562.12	119.54	681.66
140535	Bus 28 Pax	566	Mi	477.14	Mi	118.86	Mi	.42	.34	200.40	40.41	240.81
140540	Bus 40 Pax	640	Mi	506.60	Mi	134.40	Mi	.47	.60	238.10	80.64	318.74
140550	Bus 40 Pax	205	Mi	161.95	Mi	43.05	Mi	.83	.42	134.42	18.08	152.50
142101	1 Ton	161	Mi	127.19	Mi	33.81	Mi	.33	.28	41.97	9.47	51.44
142103	Panel	3218	Mi	2542.22	Mi	675.78	Mi	.20	.21	508.44	141.91	650.35
142106	1 Ton	305	Mi	240.95 95	Mi	64.05	Mi	.28	.29	67.47	18.57	86.04
142115	Ext Cab W/W	300	Mi	237.00	Mi	63.00	Mi	.47	.45	111.39	28.35	139.74
145115	3 Ton Stake	1636	Mi	1292.44	Mi	343.56	Mi	.27	.40	348.96	137.42	486.38
145116	3 Ton Stake	1802	Mi	1423.58	Mi	378.42	Mi	.29	.34	412.84	128.66	541.50
145119	3 Ton Stake	512	Mi	404.48	Mi	107.52	Mi	.29	.37	117.30	14.72	132.02

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PAGE 2 TO
ANNEX A
TO: AFFIDAVIT OF RICHARD STEWART JENNINGS
DATED: 18 SEPTEMBER 1978

D.B. Murphy, Notary Public

ECC	Type	Total No. of Miles/KM/Hrs	77/78 Miles/KM/Hrs	78/79 Miles/KM/Hrs	Total Cost Per Hour 77/78 $	Total Cost Per Hour 78/79 $	Total Cost 77/78 $	Total Cost 78/79 $	Total Cost $
146114	1 Ton	5.5 Mi	4.35 Mi	1.15 Mi	.28	.29	1.22	.33	1.55
148106	Tractor	838 Mi	662.02 Mi	175.98 Mi	.39	.43	258.19	75.67	333.86
149102	Tractor	1545 Mi	1220.60 Mi	324.40 Mi	.34	.38	415.00	123.27	538.27
149104	Tractor	934 Mi	737.86 Mi	196.14 Mi	.81	.91	597.66	178.49	776.15
158103	Tractor included with ECC 149102	1545 Mi	1220.60 Mi	324.40 Mi	.90	1.09	1,098.54	353.60	1,452.14
163123	Scoop	852 Mi	673.08 Mi	178.92 Mi	13.80	16.47	9,288.50	2,946.81	12,235.31
167115 AUX	Snow Blower	582 Mi	459.78 Mi	122.22 Mi	19.67	16.03	9,043.87	1,959.19	11,003.06
									59,677.48

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IN THE MATTER OF A CLAIM FOR COMPENSATION PRESENTED BY CANADA TO THE SOVIET UNION FOR DAMAGES INCURRED AS A RESULT OF THE INTRUSION ON CANADIAN TERRITORY ON JANUARY 24, 1978 OF THE COSMOS 954 SATELLITE LAUNCHED BY THE SOVIET UNION

5

AFFIDAVIT OF ELIZABETH STRINGER

I, Elizabeth Stringer, of the City of Ottawa, of the Province of Ontario, public servant, MAKE OATH AND SAY AS FOLLOWS:

1. I am employed in the position of Administrative Officer in the Radiation Protection Bureau, Department of National Health and Welfare of the Government of Canada and as such I have knowledge of the matters hereinafter deposed.

2. In that position my regular duties include: being aware of expenditures incurred by the Radiation Protection Bureau; being shown the invoices and other business records which document the amounts owed for services and materials rendered to the Radiation Protection Bureau; being responsible for the necessary steps to determine if these invoices and business records accurately reflect the amounts owed for services and materials rendered to the Radiation Protection Bureau.

3. Between January 24, 1978 and April 20, 1978 the Department was actively involved in the search and recovery

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operation for the debris from the Cosmos 954 Satellite. I am informed by Dr. H. Taniguchi, Chief, Environmental Radiation Hazards Division, Radiation Protection Bureau, and I verily believe that: on January 24, 1978, the Radiation Protection Bureau activated its National Radioactivity Monitoring Network, consisting of 24 air sampling stations, to collect daily samples of particulate matter in air. These samples were air-expressed to the Ottawa Laboratory to analyse for any radioactivity which may have resulted from the re-entry into the atmosphere of COSMOS 954. This search for radioactive material continued for 21 days. In addition, a new air sampling station was established at Hay River.

From the outset of the search and recovery operations, the Radiation Protection Bureau supplied radiation dosimeters to the Department of National Defence and the Atomic Energy Control Board. This monitoring of personal exposure to radiation was essential for the safety of the personnel engaged in the search and recovery. In addition to monitoring for external radiation, urine samples from these personnel were analysed for internal exposure to radioactivity.

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When finely divided radioactive particles were found south of Great Slave Lake, it became essential to determine the level of radioactivity present in snow, soil and water samples obtained from inhabited areas. A technician from the Radiation Protection Bureau was sent to Hay River, Pine Point and Yellowknife to collect the necessary samples. The samples were subsequently analysed for radioactivity in the laboratories in Ottawa.

As these radioactive particles could be ingested accidentally and could affect the drinking water supply, it was essential to characterize their radiological properties, to estimate their behaviour if ingested and to determine their solubility in ground water. These laboratory studies were carried out in Ottawa.

4. The total amount spent by the Radiation Protection Bureau to April 20, 1978 inclusive in the search and recovery operation was $18,031.11 dollars. These expenditures were incurred for the following goods and services:

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COSMOS 954 - Expenses from January 24 to April 20, 1978

Costs presented here are those incurred during the period from January 24 to April 20, 1978 by the Radiation Protection Bureau for the analyses of samples of soil, air, snow and radioactive particles collected for investigation as a result of COSMOS 954.

Travel

Cost of return travel from Ottawa to Edmonton, Hay River and Yellowknife and for accommodation on site are detailed in Annex I. Annex I(a) lists overtime expended.

Transportation of Equipment

Costs of shipping equipment to the field are listed in Annex II. These costs include transporting a survey meter, an air monitoring pump, motor and shelter to Hay River, N.W.T.

Transportation of Air, Water, Snow and Soil Samples

Costs for shipping samples from 24 air sampling stations across Canada to the Radiation Protection Bureau, Ottawa, for analyses as outlined in Annex III. Samples of snow, soil and water were also shipped from Hay River.

Materials and Supplies

Included here in Annex IV are materials and supplies purchased to ensure positive identification of samples shipped and/or taken from sampling stations and correct and accurate analyses of samples at the Radiation Protection Bureau, Ottawa.

Equipment

Cost of equipment and approved containers for collecting samples of air, water, snow and soil at Hay River and Yellowknife for analyses at the Radiation Protection Bureau are listed in Annex V.

Laboratory Analyses and Instrument Use

A cost of $50.00 per sample has been assigned for laboratory instrument time and depreciation, use of laboratory facilities and laboratory materials not specifically allocated in Annexes IV and V. The cost of these analyses is shown in Annex VI.

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Salaries

Regular salary costs representing 130 man days are listed in Annex VII.

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COSMOS 954 Expenses from Jan. 24-Apr. 20, 1978

Summary of Costs

Annex I	Travel	Sub-Total	$ 981.75
Ia	Overtime	"	390.00
Annex II	Transportation (equipment)	-	159.32
Annex III	Transportation (samples)		1564.95
Annex IV	Materials & Supplies		324.04
Annex V	Equipment		489.05
Annex VI	Laboratory Analyses & Instrument Use		4850.00
Annex VII	Salaries		9272.00
		TOTAL CLAIM	$18,031.11

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ANNEX I

TRAVEL (Ottawa to Edmonton, Hay River, Yellowknife and return)

The total cost for the Radiation Protection Bureau to maintain one (1) employee for the period March 14 to March 20, 1978 was $981.75.

Details are as follows:

Airfare via Air Canada & Pacific Western	$557.25
Accommodation - Edmonton Inn, Caribou Motor Inn, Yellowknife Inn	139.00
Meals & Incidental Expenses	122.10
Transportation & Shipping Charges	163.40
SUB TOTAL	$981.75

ANNEX I(a)

Overtime

6 man days @ $65 per day = $390.00

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COSMOS 954 Expenses from Jan. 24-Apr. 20, 1978

Annex II Transportation (Equipment)

Name of Supplier	Product or Services Supplied	Date Paid	Amount
Expidair	Charge for shipment of equipment (survey meter)	10/3/78	$ 55.00
Air Canada Cargo	Charge for shipment of equipment (shelter, pump & motor)	15/3/78	104.32
Sub Total			$159.32

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COSMOS 954 Expenses from Jan. 24-Apr. 20, 1978

Annex III Transportation (Samples)

Name of Supplier	Product or Service Supplied	Date Paid	Amount
CP Air	Charges for transportation of samples from sampling stations to RPB for analysis	Jan. 24-Apr. 20	$1420.45
Pacific Western Air	Charges for transportation of samples from sampling stations to RPB for analysis	Jan. 24-Apr. 20	85.50
Transair	Charges for transportation of samples from sampling stations to RPB for analysis	Jan. 24-Apr. 20	59.00
Sub Total			$1564.95

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COSMOS 954 Expenses from Jan. 24-Apr. 20, 1978

Annex IV Materials and Supplies

Name of Supplier	Product or Service Supplied	Date Paid	Amount
Canus Plastics	Metal cans with lids	22/3/78	$30.00
Canus Plastics	3 gallon pails	11/3/78	51.84
Canus Plastics	Acrylic tubing	11/3/78	8.56
Dept'l Stores	Cards for 24 stations for 21 days	29/3/78	20.16
	Reply envelopes for 24 stations for 21 days	29/3/78	20.16
	Containers with caps	10/3/78	6.48
	Kimwipes, tags	14/3/78	6.40
	Glass filters	6/3/78	18.00
	Reagents (Scintillator Solution)	6/3/78	60.00
	Sampling bottles	6/3/78	10.00
	Vials	6/3/78	4.00
	Glass filters	7/2/78	88.44
Sub Total			$324.04

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COSMOS 954 Expenses from Jan. 24-Apr. 20, 1978

Annex V Equipment

Name of Supplier	Product on Service Supplied	Date Paid	Amount
Dept's Stores	Vacuum Pump	6/3/78	$369.00
	1/2 H.P. motor	6/3/78	100.00
	Vacuum gauge	6/3/78	7.50
	Vacuum belt	6/3/78	1.09
Beaver Lumber	Plywood and nails	11/3/78	8.17
	Plumbers tape & film	15/3/78	3.29
Sub Total			$489.05

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ANNEX VI

Laboratory Analyses and Instrument Use

Gamma spectrometric analyses of air filters	$2100.00
Gamma spectrometric analyses of precipitation	250.00
Study of solubility of particles	1000.00
Liquid scintillation counting and gamma spectroscopy	1500.00
SUB-TOTAL	$4850.00

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ANNEX VII

SALARIES

Nature of Investigation	Man Days	Salary
Environmental Monitoring	48	3115
Solubility Studies	14	1010
Bio-assay	11	807
Film Monitoring	22	1100
Co-ordination & Management	35	3240
TOTAL	130	9272

5. The accounts, vouchers, receipts and other records relating to these expenses are in my control at the City of Ottawa.

SWORN BEFORE ME IN THE CITY OF)
OTTAWA, IN THE REGIONAL)
MUNICIPALITY OF OTTAWA-)
CARLETON THIS 28th DAY OF)
SEPTEMBER, A.D. 1978.)

Richard Thorn Jr. [signature]

A Commissioner etc.

my Commission expires 6 December 1980

Elizabeth Stronge [signature]

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6

IN THE MATTER OF A CLAIM FOR COMPENSATION PRESENTED BY CANADA TO THE SOVIET UNION FOR DAMAGES INCURRED AS A RESULT OF THE INTRUSION ON CANADIAN TERRITORY ON JANUARY 24, 1978 OF THE COSMOS 954 SATELLITE LAUNCHED BY THE SOVIET UNION

AFFIDAVIT OF BRIAN THOMAS LYNCH

I, BRIAN THOMAS LYNCH, of the City of Ottawa, of the Province of Ontario, public servant, MAKE OATH AND SAY AS FOLLOWS:

1. I am employed in the position of Chief Accounting Officer of the Royal Canadian Mounted Police (hereinafter referred to as the "R.C.M.P.") and as such I have knowledge of the matters hereinafter deposed.

2. In that position my regular duties include: being aware of expenditures incurred by the R.C.M.P.; being shown the invoices and other business records which document the amounts owed for services and materials rendered to the R.C.M.P.; being responsible for the necessary steps to determine if these invoices and business records accurately reflect the amounts owed for services and materials rendered to the R.C.M.P.; being certain that payments are made to the persons and the companies who have submitted the invoices and other business records for these services and materials rendered to the R.C.M.P.; and, being responsible for the administration of the salary expenditures to the employees of the R.C.M.P.

3. Between January 24, 1978 and April 20, 1978 the R.C.M.P. was actively involved in the search and recovery operation for the debris from the Cosmos 954 Satellite.

4. I am informed by Insp. C.R. Latremouille, who is the Officer in Charge Administration and Personnel of the R.C.M.P.

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"G" Division at Yellowknife, Northwest Territories, and I verily believe that:

(a) On January 29, 1978 satellite debris was located at McLeod Bay on Great Slave Lake (Fort Reliance area), Northwest Territories.

(b) On January 29, 1978 members of the R.C.M.P. provided escort for four possibly contaminated persons at Warden's Grove when they were brought to Yellowknife for examination. This consisted of an escort from the airport to the hospital and a check of the hospital for security purposes prior to DND personnel taking over the guarding of these individuals.

(c) On January 30, 1978 two members of the R.C.M.P. were sent to McLeod Bay to assist DND personnel in guarding the scene; these members were withdrawn from the site of February 5, 1978; the members at the site were rotated during this period.

(d) On January 30, 1978 a member of the R.C.M.P. was sent to guard the satellite debris located in the Warden's Grove, Northwest Territories area; this member was withdrawn from the site on February 6, 1978. The member at the site was rotated during this period.

(e) On January 31, 1978 a second member of the R.C.M.P. was sent to the Warden's Grove area to assist. This member was withdrawn from the site on February 6, 1978. The member at the site was rotated during this period.

(f) On January 30, 1978 a member from Snowdrift Detachment

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of the R.C.M.P. patrolled to Fort Reliance, Northwest Territories, and cabins in the surrounding area via police aircraft to inform people of the location of satellite debris and radioactive material and warn them to stay clear of the affected area.

(g) Members of the R.C.M.P. at Yellowknife guarded exhibits of radioactive material brought into Yellowknife for shipment to southern points from approximately 1800 hours January 31, 1978 to approximately 1030 hours February 2, 1978.

(h) On February 10, 1978 radioactive material was located in an area approximately four miles west of Snowdrift, Northwest Territories on Great Slave Lake. A member of Snowdrift Detachment of the R.C.M.P. attended the scene immediately and was replaced later the same date by a member of Yellowknife Detachment of the R.C.M.P. who remained at the site until February 13, 1978.

(i) In addition to the foregoing specific incidents involving our members, daily liaison was maintained with local military personnel as well as members of Atomic Energy Control Board. This included meetings during staging segments of the operation. Administrative and operational personnel were also required from time to time to arrange for guards at debris sites, arrange for aircraft, check out reports concerning the sighting of the satellite and provide transportation for members involved in the operation.

5. The total amount spent by the R.C.M.P. to April 20, 1978 inclusive in the search and recovery operation was fourteen

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thousand five hundred and thirty-two dollars and eighty-five cents ($14,532.85). These expenditures were incurred for the following goods and services:

(a) Travel:

Costs of travelling from Yellowknife, Northwest Territories to the McLeod Bay and Warden's Grove areas and return as required, are summarized in Annex 1.

(b) Materials and Supplies:

Annex 11 lists supplies purchased to operate single side band radios and portable radios.

(c) Salaries:

Annex 111 lists the salaries for those members of the R.C.M.P. involved in Operation Morning Light from January 24, 1978 to April 20, 1978. This tabulation also shows the cost of recorded overtime hours, converted overtime hours, and the dollar equivalent of this.

6. The accounts, vouchers, receipts and other records relating to these expenses are in my control at the City of Ottawa.

SWORN BEFORE ME IN THE)
CITY OF OTTAWA, IN THE)
REGIONAL MUNICIPALITY)
OF OTTAWA-CARLETON)
THIS 31 DAY OF)
August A.D. 1978.)

R. Jackson

Ronald C. Jackson, a Commissioner For Taking Affidavits. Judicial District of Ottawa-Carleton, for The Royal Canadian Mounted Police.
Expires June 1980

Brian Thomas Lynch

Brian Thomas Lynch

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ANNEX 1

TRAVEL (Yellowknife to McLeod Bay and Warden's Grove areas, and return as required)

The total travel cost incurred by the R.C.M.P. in connection with Operation Morning Light for the period January 24 to April 20, 1978 is $8,830.58.

No travel costs were incurred by the R.C.M.P. for the period April 21, 1978 to the present.

Pre - April 20

Police Aircraft		
Single Otter - 12.2 hours x 110 m.p.h. (average) = 1,342 miles x $3.82 per mile =	$5,126.44	
Twin Otter - 10.1 hours x 160 m.p.h. (average) = 1,616 miles x $1.99 per mile =	$3,215.84	$8,342.28
Police Car 500 miles @ 20¢ per mile		$ 100.00
Oversnow Vehicle 6 hours @ $2.50		$ 15.00
Meals & Incidentals		$ 373.30
	Sub-Total -	$8,830.58

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ANNEX 11

MATERIALS AND SUPPLIES

NAME OF SUPPLIER	PRODUCT OR SERVICE SUPPLIED	DATE PAID	AMOUNT
Cardinal Industrial Electronics Ltd.	Nine CH 4 batteries for single side band radios	June 27/77	$78.72
MacLeods Merchandisers Ltd.	Five batteries for portable radios	Feb. 2/78	$15.95
		Sub-Total	$94.67

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ANNEX 111

SALARY EXPENDITURES JANUARY 24, 1978 TO APRIL 20, 1978

	REGULAR TIME			OVERTIME			
NAME	HOURS	RATE	TOTAL	HOURS	CONVERTED OVERTIME	RATE	TOTAL
HORSMAN, G.R.	4	9.52	38.08				
WISHNOWSKI, L.V.				3.5	5	9.10	45.50
OTTMAN, W.B.				4.5	7	8.34	58.38
OTTMAN, W.B.	40	8.34	333.60				
REINHARDT, R.P.	40	9.10	364.00				
WALKER, S.K.	4	9.10	36.40				
ARMSTRONG, J.A.	1	11.58	11.58				
ARMSTRONG, J.A.	1	11.58	11.58				
ARMSTRONG, J.A.	8	11.58	92.64				
ARMSTRONG, J.A.	8	11.58	92.64				
ARMSTRONG, J.A.	5	11.58	57.90				
ARMSTRONG, J.A.	5	11.58	57.90				
ARMSTRONG, J.A.	1	11.58	11.58				
ARMSTRONG, J.A.	1	11.58	11.58				
ARMSTRONG, J.A.	2	11.58	23.16				
PHELAN, A.				4	6	6.39	38.34
HOBBS, R.W.	1.5	9.10	13.65				
HARTWIG, B.H.	1.5	9.10	13.65				
DRISDELLE, J.J.R.	.5	9.10	4.55	2	3	9.10	27.30
WESTWOOD, A.K.	2.5	9.88	24.70				
NORTH, E.	3	9.10	27.30				
HARRISON, R.S.	4	9.10	36.40				
LUCHTMEIJER, W.	3	9.10	27.30				
LUCHTMEIJER, W.	1	9.10	9.10	5	7.5	9.10	68.25
LUCHTMEIJER, W.	8	9.10	72.80	5	7.5	9.10	68.25
LUCHTMEIJER, W.	8	9.10	72.80				
LUCHTMEIJER, W.				8	12	9.10	109.20
McCARTHY, R.G.H.	3	9.88	29.64				

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NAME	REGULAR TIME HOURS	RATE	TOTAL	OVERTIME HOURS	CONVERTED OVERTIME	RATE	TOTAL
McCARTHY, R.G.H.	3	9.88	29.64				
WOODS, R.G.	8	8.34	66.72				
WOODS, R.G.	8	8.34	66.72				
WOODS, R.G.	8	8.34	66.72				
LUCHTMEIJER, W.				8	12	9.10	109.20
LUCHTMEIJER, W.				8	12	9.10	109.20
LUCHTMEIJER, W.				8	12	9.10	109.20
REID, W.D.				1.5	2	9.88	19.76
REID, W.D.				11	16.5	9.88	163.02
REID, W.D.				8	12	9.88	118.56
REID, W.D.				4.5	7	9.88	69.16
SABEY, A.L.	4	11.58	46.32				
SABEY, A.L.	7	11.58	81.06				
SABEY, A.L.				8	12	11.58	138.96
ECCLESTON, J.L.	8	8.09	64.72				
ECCLESTON, J.L.				3.5	5	8.09	40.45
LOK, K.	3	9.52	28.56				
GRINSTEAD, R.J.	3	9.52	28.56				
GRINSTEAD, R.J.	3	9.52	28.56				
GRINSTEAD, R.J.	2	9.52	19.04				
GRINSTEAD, R.J.	2	9.52	19.04				
GRINSTEAD, R.J.	1	9.52	9.52				
GRINSTEAD, R.J.	1	9.52	9.52				
GRINSTEAD, R.J.	1	9.52	9.52				
GRINSTEAD, R.J.	8	7.62	60.96				
GRINSTEAD, R.J.	8	7.62	60.96				
GRINSTEAD, R.J.	8	7.62	60.96				
GRINSTEAD, R.J.	8	7.62	60.96				
GRINSTEAD, R.J.				8	12	7.62	91.44
GRINSTEAD, R.J.				8	12	7.62	91.44
GRINSTEAD, R.J.	8	7.62	60.96				
GRINSTEAD, R.J.	8	7.62	60.96				

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NAME	REGULAR TIME HOURS	REGULAR TIME RATE	REGULAR TIME TOTAL	OVERTIME HOURS	OVERTIME CONVERTED OVERTIME	OVERTIME RATE	OVERTIME TOTAL
GRINSTEAD, R.J.	4	7.62	30.48				
BOWDEN, A.A.	12	6.47	77.64				
BOWDEN, A.A.	12	6.47	77.64				
BOWDEN, A.A.	13	6.47	84.11				
BOWDEN, A.A.	12	6.47	77.64				
BOWDEN, A.A.	4	6.47	25.88				
MacKENZIE, A.A.	8	9.10	72.80	4	6	9.10	54.60
MacKENZIE, A.A.	8	9.10	72.80	4	6	9.10	54.60
MacKENZIE, A.A.	8	9.10	72.80	5	7.5	9.10	68.25
MacKENZIE, A.A.	8	9.10	72.80	4	6	9.10	54.60
MacKENZIE, A.A.	4	9.10	36.40				
GREBER, L.A.	6	9.52	57.12				
RAYNER,	4	8.34	33.36				
RAYNER,	8	8.34	66.72				
RAYNER,	8	8.34	66.72				
RAYNER,	8	8.34	66.72				
RAYNER,	8	8.34	66.72				
RAYNER,	8	8.34	66.72				
RAYNER,	4	8.34	33.36				
RECHNER, G.	16	13.20	211.20				
LAMBERT, J.G.	10	11.58	115.80				

TOTAL REGULAR TIME SALARIES - - - $3,899.94
TOTAL OVERTIME SALARIES - - - - $1,707.66

TOTAL SALARIES $5,607.60

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RCMP GRC **TRANSIT SLIP** ***FICHE DE SERVICE***

BIN / BD

Classification

File No. – *N° du dossier* GTS 1582-2

• HANDWRITE – *ÉCRIRE À LA MAIN*

TO – *À*	FROM – *DE*	Date
Vedic Records Supervisor	NCO i/c Emergency Preparedness Section	88-11-16
Terry Cameron Archives Unit.	Pat Schieman Vedic Records	88-11-21

☐ Comments / *Commentaires* ☐ Action / *Donner suite* ☐ Prepare Brief / *Préparer un exposé* ☐ Return with Current File / *Retourner avec le dossier actuel*

☐ Perusal and P.A. / *Lire et classer* ☐ Prepare Reply / *Rédiger une réponse* ☐ Make File(s) / *Ouvrir un dossier* ☐ Check Records / *Vérifier les dossiers*

SUBJECT – *SUJET* Emergency Preparedness Files for Archives

REMARKS (Use same A-5 for Reply when space permits) – *REMARQUES (Si l'espace le permet, répondre sur cette formule)*

Sgt. G. F. Arnott and the undersigned examined contents of our directorate files in boxes 1 to 22. In all cases, the file material touches on policy matters or other topics which have long been declared obsolete or redundant. We have no further use for any of this dead material and recommend that you reduce it to archives storage.

[signature]

Terry;

This memo should cover all areas. In my opinion these files are all Historical.

Thank you for your help.

Enclosed 22 Boxes Secret, Top Secret & NATO.

Pat.

Diary Date – *Date d'agenda*	Meeting Date – *Date de réunion*	P.A. – *A.C.* Date	Init./*N°*
			001384

A-5 (80-08) 7530-21-029-4767

Document disclosed under the *Access to Information Act* -
Document divulgué en vertu de la *Loi sur l'accès à l'information*

RECORDS MANAGEMENT – C.I.B. CLASSIFICATION AND CHECK SHEET
GESTION DES DOSSIERS – FEUILLE DE CLASSEMENT ET DE CONTRÔLE DU SEJ

CLASSIFIER	CLASSIFICATEUR
INITIALS – *INITIALES* Pat	DATE 79/2/14

FILE No – *N° DU DOSSIER*
HQP 485-35
Supp A

NAME – *NOM*

CARDED

Operation Morninglight

ADDRESSES – *ADRESSES*

DATE AND PLACE OF BIRTH – *DATE ET LIEU DE NAISSANCE*	F.P.S.	CHECKED – *VÉRIFIÉ* INITIALS – *INITIALES*	DATE

FILE REFERENCES – *DOSSIERS À CONSULTER*	FILE REFERENCES – *DOSSIERS À CONSULTER*

C-75A (REV. 4/71) (7530-21-029-4832)