COSMOS 954 - A CASE STUDY

Address by Dr K H Lokan

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On September 18th 1977 Cosmos 954, a nuclear-powered satellite, was launched by the USSR. Within weeks of its launching it showed abnormal behaviour and its eventual re-entry was anticipated within a few months. By January 1978 it was recognised that re-entry was likely within the month, and the US Government, which had been tracking it closely, alerted all countries which could possibly be affected (including Australia) on January 19th 1978. In the event, the satellite re-entered the atmosphere in the Northern hemisphere in the early hours of January 24th, and parts of it reached the surface of the earth in the Yellowknife area, Northwest Territories (see Figure 1).

Although the USSR had stated that the vehicle was designed to burn up and disintegrate on re-entry, a major field program was at once set up by the Canadian Government to search for and retrieve any radioactive material. This continued from January (Phase I) with a pause during the spring thaw, until October 1978 (Phase II). Co-ordination, logistics and overall direction of this program were assigned to the Department of National Defence, while responsibility for the recovery, handling and management of debris was given to the Atomic Energy Control Board (AECB). Scientists and support staff were drawn from many sources, including the Geological Survey of Canada (who had facilities for airborne uranium exploration) the nuclear research laboratories of Atomic Energy of Canada Ltd, and the AECB itself. A substantial Canadian team, based on Edmonton and Yellowknife was in place within days. In addition the US Government made available its Nuclear Emergency Search Team (NEST) organised several years earlier by the Department of Energy, which had been on standby and preparing for re-entry for several weeks. At its peak, there were some 250 Canadians and about 120 Americans involved in search and recovery in the field, operating in a virtually uninhabited part of the country under severe arctic conditions where temperatures reach -40°C, or as low as an effective -100°C with wind chill factor.

Little information on the nature of the reactor was provided by the USSR, but from the material recovered, it seems evident that it was a fast reactor, fuelled with about 20 Kg of uranium enriched to 90% in the isotope U-235, with a thick beryllium reflector. Assuming that it operated from launch to re-entry at a probable power level of 100 kilowatt, the total fission product inventory is estimated to have been about 500,000 curies. Much of this activity would be very shortlived and by April 1st 1978, it would have decayed to 13,000 curies. One year after re-entry it would have decayed further to about 2000 curies. Because of the remoteness of the area, its low population and the modest quantities of radioactive materials believed to have reached the ground, the situation scarcely qualifies as a major nuclear disaster. However, under different circumstances, it could have been quite significant and it is useful to study it from this perspective.

Detection of Radioactive Debris

In general the method used to detect fission products is to seek the energetic gamma rays (high energy X rays) which they emit. The problem in this case was complicated by the fact that the search area happens to be rich in uranium and thus has an anomalously high gamma ray background. Simple counting of the total number of gamma rays is not therefore very specific. However, by taking advantage of the fact that fission product gamma rays generally have a lower average energy than those from uranium, a selective indicator is obtained from the ratio of low to high energy components. This is illustrated in Figure 2, where figure 2b pinpoints a source containing fission products and ignores the generally higher background observed over land than over water (Fig. 2a).

The initial search procedure consisted of flying traverses at 1 mile intervals across the re-entry path at a height of 500 metres, with an airborne gamma ray scintillator counter. Data were collected on magnetic tape, and quickly analysed to distinguish between natural and man made radioactivity. As suspected debris was identified the search grid was refined, and ultimately a ground search with hand monitors was used to locate and assess the material prior to its removal. As material was located it became evident that most had been deposited in a strip a few kilometres wide roughly along the line of re-entry but slightly displaced southwards by wind drift. A microwave ranging system proved invaluable to pinpoint locations on the ground which had been previously identified from the air.

Fragments recovered ranged in size from ∼50cm (excluding the "antlers", a stainless steel and boron structure - probably part of the reactor control system - which was found by chance some 300 km further down range) down to particles of less than 100 microns. Most were radioactive, some of them indeed very much so.

Outside of this well defined strip there were deposited over a very large area to the south, finely divided particles of uranium fuel. In all, several thousand of these were recovered, during both the winter and summer time searches. In general the finer the particle (and the less active) the further south they were found, so that the southern boundary is not well defined. Many particles were recovered near NWT communities south of Great Slave Lake, but significant numbers were also retrieved from roads, railways, cottages, lodges, etc. in the affected region. The area affected is very large, in excess of 100,000 sq. km. Careful ground surveys were carried out in all reasonably accessible and inhabited regions to ensure that no significant health hazard remained. A few particles have been found subsequently by prospectors.

It is difficult to estimate accurately how much of the original reactor core reached the surface of the earth. In terms of the original inventory of 13,000 Curies as at April 1st 1978, the GSC estimated that the total deposited on Great Slave Lake is 700 Curies (obtained by integrating the excess activity over natural background above the lake surface, where backgrounds are low). Similarly by sampling many other lakes, they estimated that roughly 2500 Curies - or 20% of the total inventory was deposited overall. That is to say about 4Kg of the original core. The remainder, as stated by the Russians has probably remained in the upper atmosphere*, and will gradually be deposited along with fallout from atmospheric nuclear tests. Its significance is slight compared with existing atmospheric fallout.

Health Implications

The search and recovery program no doubt retrieved most fragments of significant size deposited in the well defined belt along the re-entry path. Any which were missed would almost certainly have sunk to the bottom of Great Slave Lake, and are thus effectively removed from the environment. The smaller uranium particles however fell in great numbers over a wide area. Much of their radioactivity would have decayed rapidly, as most fission products are quite short lived. Of the longer lived and usually important radionuclides caesium-137 and strontium-90 there is good evidence from the particles recovered that they were "boiled off" during re-entry. In any case the total inventory of these isotopes in a small reactor of this type if quite small ($\sim$ 50 curies) and the Canadians estimate that if all of it had come down it would correspond to a deposition per square metre of about one fourteenth of the annual deposit received in Yellowknife from the residues of atmospheric nuclear testing.

It was assumed that the widely dispersed fuel particles would, following the spring thaw, work their way downwards into water courses and lakes. In general the uranium itself is very insoluble, and thus unlikely to enter the food chain. The fission products are of course decaying with time and, as mentioned above, the volatile Cs-137 and Sr-90 are absent from the material which reached the ground. No trace of radioactivity attributable to Cosmos-954 has been detected in community water supplies in the region, nor in any of the wild life.

Conclusions

Because all obvious fragments had been retrieved, and because of the rapidly diminishing radiological risk from the fuel particles, relative to natural background,

* high altitude air sampling during 1978 confirmed the presence of significant quantities of 90% enriched uranium in the upper atmosphere between 30 and 40 km.

a calculated decision was taken to discontinue the search and recovery program in October 1978. The Canadian Government felt that it could take this step with confidence, because of the extent of its program, the thorough analysis and research carried out on the material which had been recovered, and its careful assessment that health consequences would be slight and diminishing because of the nature of the (unrecovered) debris, and the isolation of the region. By its conclusion, the operation had cost the Canadian Government almost C$14,000,000.

The synopsis given above has been derived from a report published by the AECB*.

It is useful to conclude by reprinting Appendix H to this report, entitled -

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.

* "COSMOS-954 The occurrence and nature of recovered debris" AECB Report INFO-0006 May 1980.

A very readable but less authoritative journalist's account has been published in book form as Operation Morning Light by Leo Heaps (Paddington Press, London 1978).

To meet these requirements required assistance from NORAD and US expertise for the trajectory, and involved coördinated 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 recognised.

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 see 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 air-borne 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 accounted in a standardised fashion by all participating agencies, in order to permit prompt preparation of eventual financial claims.

It might be suggested that the UN Committee of 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 UN Disaster Organisation is another possibility. Such an organisation 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 organising 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.

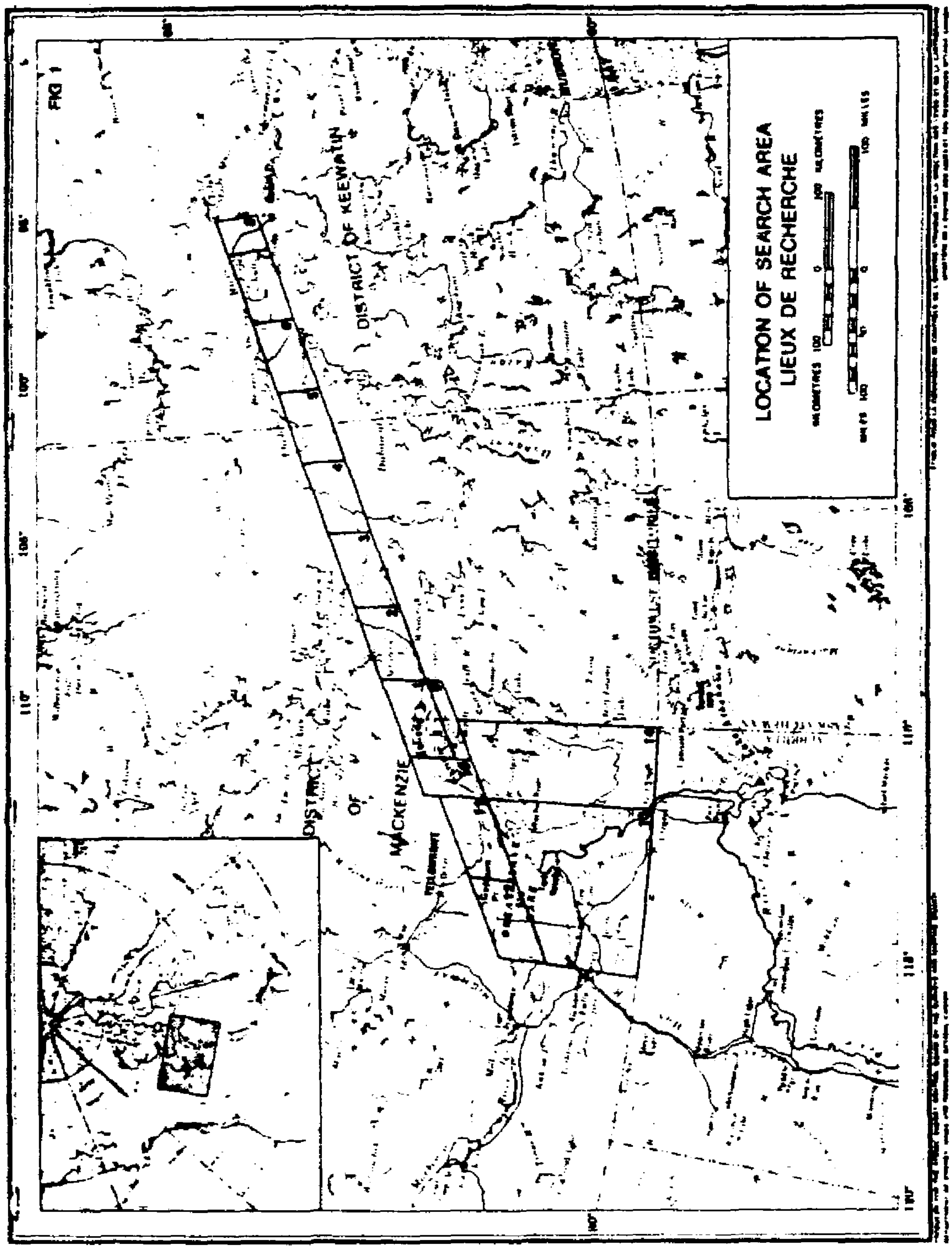
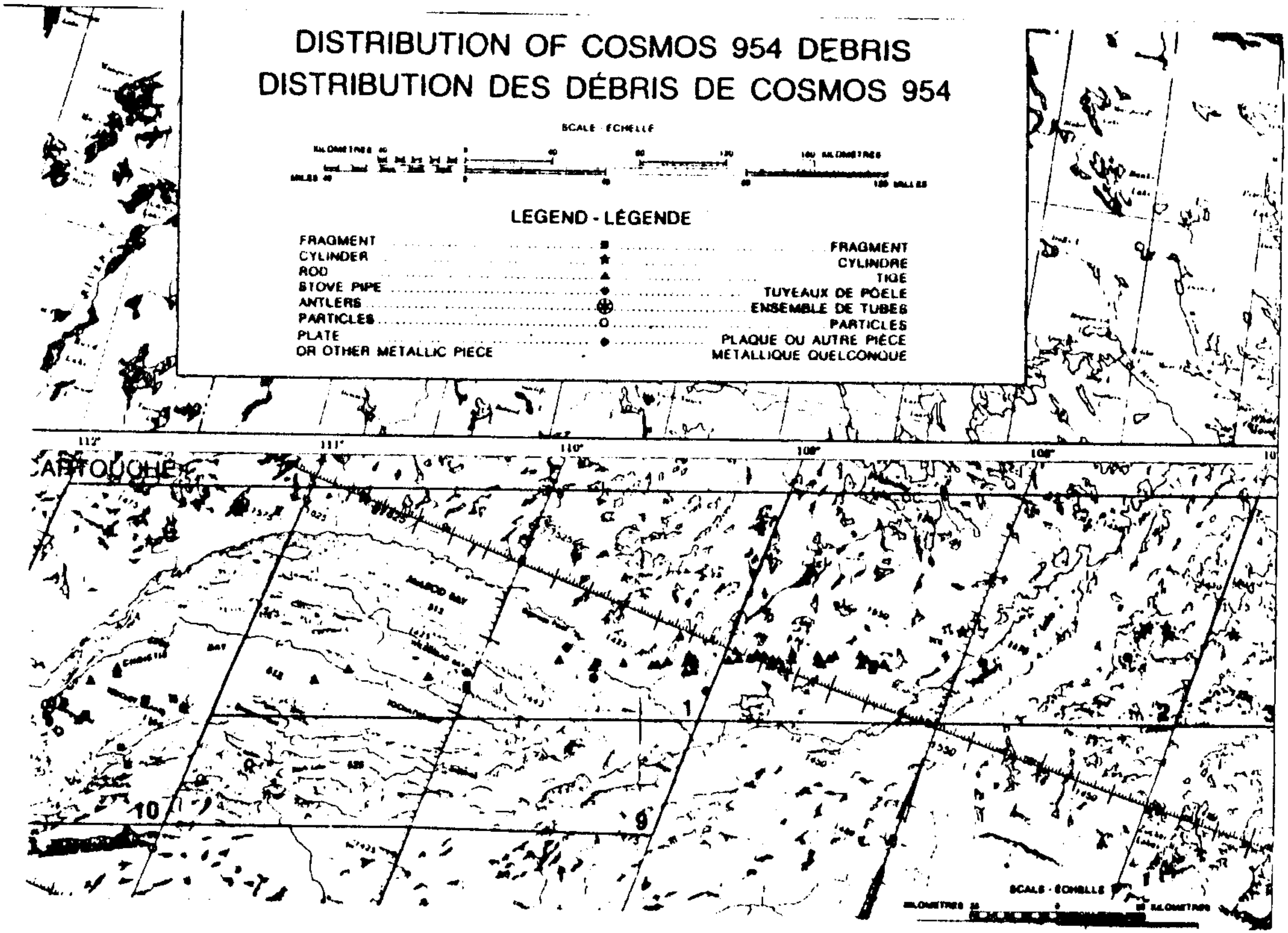
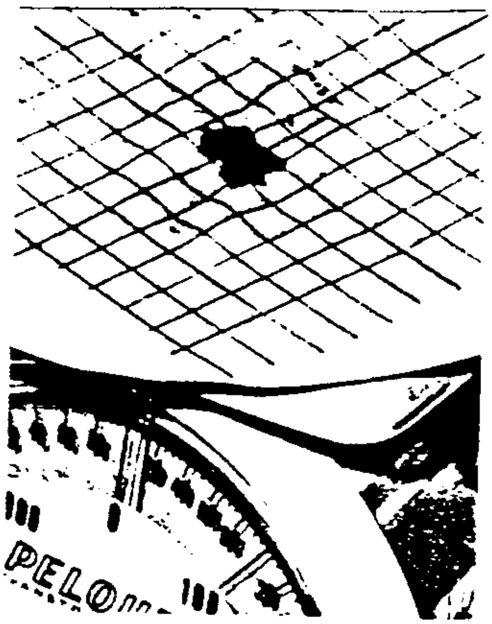
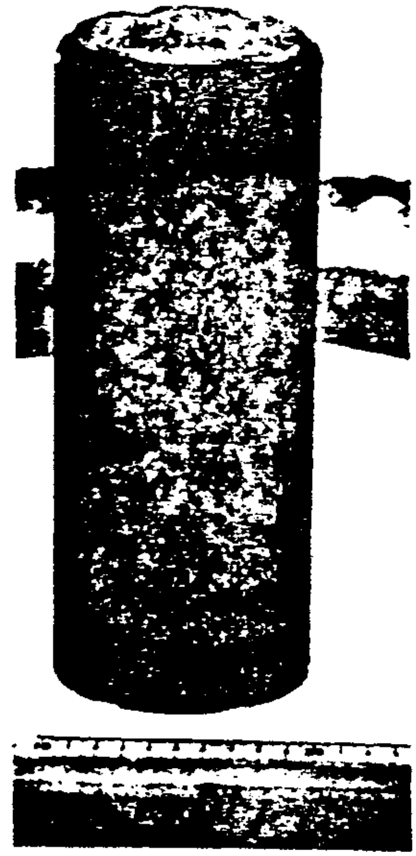


FIGURE 1 Location of area of fall, showing search sectors


DISTRIBUTION OF COSMOS 954 DEBRIS
DISTRIBUTION DES DÉBRIS DE COSMOS 954
SCALE · ECHELLE
LEGEND - LÉGENDE
FRAGMENT ... FRAGMENT
CYLINDER ... CYLINDRE
ROD ... TIGE
STOVE PIPE ... TUYEAUX DE POELE
ANTLERS ... ENSEMBLE DE TUBES
PARTICLES ... PARTICLES
PLATE OR OTHER METALLIC PIECE ... PLAQUE OU AUTRE PIÈCE METALLIQUE QUELCONQUE
112°
111°
110°
109°
108°
CARTOUCHE
1
2
9
10
SCALE · ECHELLE



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



One of six beryllium cylinders. Mu 29/2. Note the generally unaltered appearance of the surface

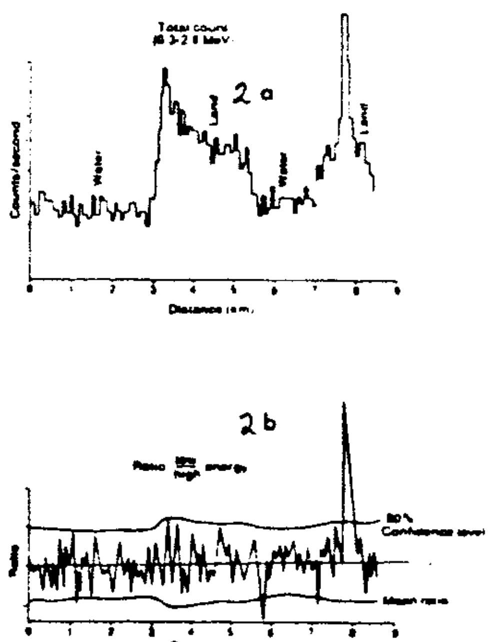
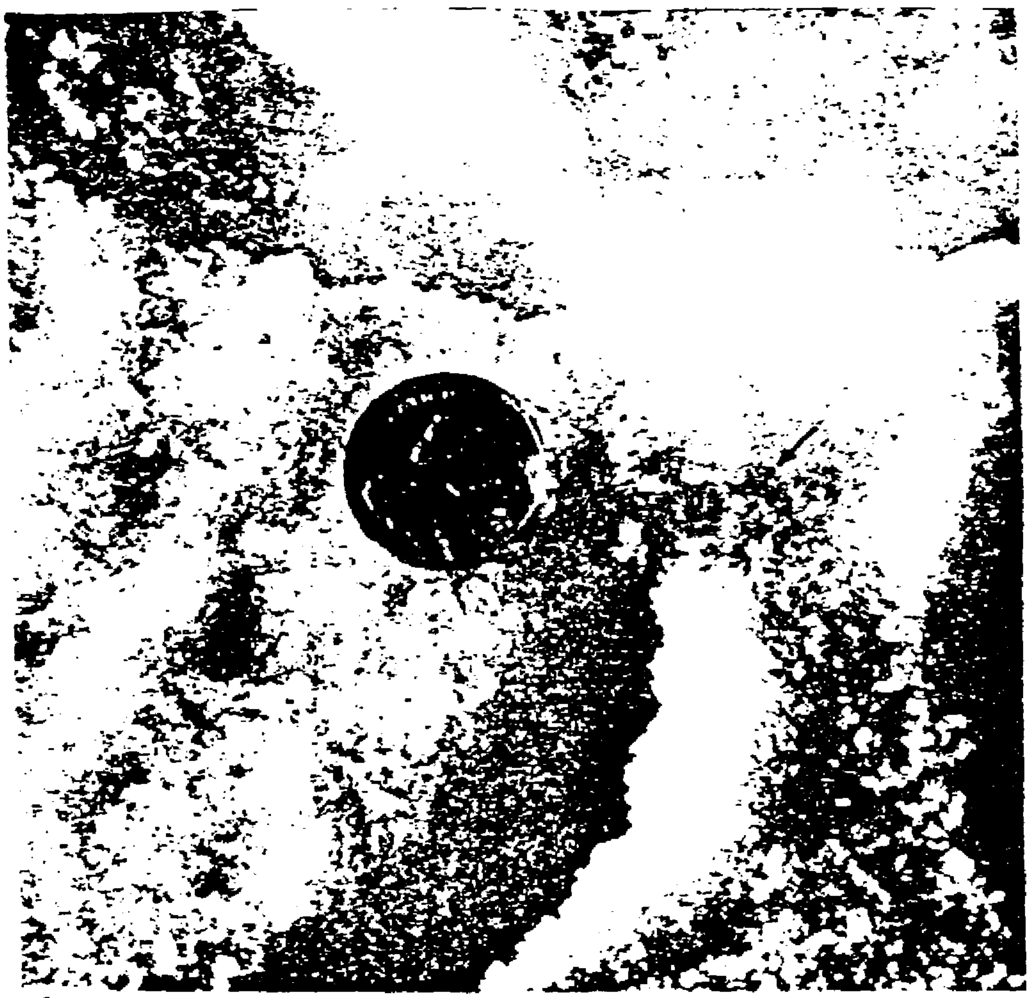


FIGURE 5 Example of procedure used to detect radioactive satellite debris (the high peak in each case)

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



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.

EMERGENCY TREATMENT OF RADIATION CASUALTIES

Address by Surgeon Commander K DELANEY RAN

NUCLEAR RADIATION - THE PROBLEM

This paper will examine radiation effects primarily in the context of a nuclear weapons explosion. Other circumstances relevant to this NDO Study, in which radiation casualties may occur, such as nuclear power reactor and criticality accidents or exposure to high level radioactive sources, produce essentially the same pattern of radiation injury.

Types of Nuclear Radiation

Nuclear radiation may be either electromagnetic (ie gamma or X-rays) or particulate (ie alpha or beta particles or neutrons). Injury may result from exposure to the radiation field, or by contamination by a radioactive compound.

Incident irradiation may cause injury to the whole body, or a part thereof if the body is partly shielded or the radiation colimated. Of greatest practical significance in this circumstance are gamma rays, X-rays and neutrons. Each of these radiations has a large range in air and achieves significant penetration of tissue. Individually, these radiations have varying capacity to produce tissue injury, dependent on characterisation of the particular radiation, in particular:

a. Linear energy transfer (LET), which is the average energy (KeV) released per unit track length (uM).

b. Relative biological effectiveness (RBE), which is the ratio of the absorbed dose (Gy or Rad) of one type of radiation required to produce a biological effect, to the absorbed dose of a nominated baseline radiation required to produce the same effects, and

c. Distribution of dose in time, ie dose ratio or fractionation.

Contamination by radioactive compounds may cause either an external or internal injury. Radiations of significance here are gamma, beta and alpha. External contamination occurs when the radioactive compound is deposited on the skin. Internal contamination occurs when the radioactive compound is inhaled, ingested, injected or absorbed via the skin (directly or through a wound). Apart from the characteristics mentioned above tissue injury following radioactive contamination is dependent on the following features:

a. Penetration. Gamma rays are highly penetrating of tissue. Alpha and beta particles have little

142. a. (continued)

penetrating power, the former being fully absorbed by 20 micro meters of tissue, the latter able to penetrate only a few millimeters of tissue. Hence alpha and beta contamination results in local injury, whereas gamma contamination can result in lethal doses of whole body radiation. Penetration is expressed more exactly by the half value layer for that radiation for a nominated absorber, eg water.

b. Effective half life. (TE) For compounds involved in internal contamination, the biological half life (TB) and the radioactive half life (TR) together determine the duration of exposure of the body to that source of internal contamination. This characteristic is expressed as

$$\frac{1}{TE} = \frac{1}{TB} + \frac{1}{TR}.$$

It is most significant for compounds with both long radioactive and long biological half lives, such as the bone trapped Strontium-90 or the thyroid trapped Iodine-131.

Nuclear weapons, nuclear radiation

The radiation sequelae of a NW explosion are defined as initial or prompt radiation and residual radiation.

Initial radiation: is that nuclear radiation occurring in the first minute after explosion. It is composed of neutrons, gamma rays, X-rays, beta particles; highly energetic and ionised fission fragments; and gamma rays and beta particles arising from the shorter half life fission products. Only the neutrons and high energy photons are important when considering casualty infliction. The ratio of gamma photon to neutrons in the initial radiation and so the RBE of that radiation, varies with the distance from the explosion, as well as with the type of weapon. For example, a gamma/neutron ratio of 1:3 close to GZ may change to 3:1 at a point distant from GZ.

Residual radiation: is defined as those radiations emitted greater than 1 minute after detonation. It consists of gamma rays, beta particles and alpha particles, emitted by fission products, unfissioned nuclear material and neutron-induced radioactive fragments of weapon and environmental debris. These radiations form fallout, which may be local, ie in the general vicinity of the detonation, or distant "world-wide" fallout. Local fallout is of greater immediate concern. This occurs when fireball contacts the ground or water, causing vast quantities of environmental material to become radioactive, with deposition back to ground from the mushroom cloud occurring over considerable time and distance beyond the range of thermal and blast casualty effects.

Both incident radiation by gamma emitting radioactive compounds, and contamination with beta, alpha and gamma emitting compounds are important when considering casualty infliction. In the case of fallout, the meteorological situation and particle size of the radioactive compound are also important in determining extent and location of casualties.

<u>Compound trauma</u>. In nuclear reactor accidents, criticality accidents or exposure to high level sources, casualties will develop a "pure" radiation injury. With a NWE, the radiation injury may be combined with or overshadowed by the thermal or blast injury. Depending on the type of NWE, (ie surface burst - air burst - high air burst etc.) the proportion of energy released contributing to nuclear irradiation varies between about 5 and 20% of total energy released by the weapon. The remainder of the energy is given off as thermal radiation and blast. Therefore co-existent injuries due to nuclear, thermal radiaticn and blast occur. The predominant injury depends on several factors:

a. yield of weapon;

b. distance from gound zero (GZ):

c. type of weapon burst;

d. the nature of the environment, as it affects the degree of physical protection or exposure to physical trauma.

A useful rule of thumb is that for weapons with a yield greater than 50Kt initial radiation can be ignored and severe local fallout following a surface burst (ie nuclear radiation casualties) can extend beyond the thermal and blast effects.

If factor d. above is ignored then casualty effects (and other parameters) can be predicted for various ranges from GZ for a given yield NWE. These predictions utilise data from NWE, as published in "The Effects of Nuclear Weapons" by S Glasstone, and are able to be determined by using a pocket calculator provided as a component of that reference. In this manner, the familiar 'circles of devastation' diagrams, superimposed on maps of familiar capital cities like Melbourne, are observed.

An illustration of the difference in range of effects between 1 Kt, 20 Kt and a 10Mt fission - fusion weapon, and the effects of the pattern of radiation casualties, is given in the following chart (Table 1) (range in Km).

	1000rem no survivors	.67	100rem minimum casualties	.99
1 Kt	3^{o} burn	.66	1^{o} burn	.83
	1000rem	1.2	100rem	1.6
20 Kt	3^{o} burn	2.8	1^{o} burn	4.4
	1000rem	3.8	100rem	4.8
10Mt	3^{o} burn	32	1^{o} burn	40

It will be evident from this data that although compount injuries will always result from an NWE, the casualty load due to injuries solely resulting from nuclear radiation, or with nuclear radiation as part of the compound injury will be proportionately greater with smaller tactical nuclear weapons.

CASUALTIES - THE CLINICAL EFFECTS OF NUCLEAR RADIATION

The acute radiation syndrome describes a sequence of disorders which develop after exposure to a substantial dose of ionising radiation (more than 75 rad) to the whole body or a major part of the body. It involves primarily four organ systems:

a. Haematopoietic

b. Gastrointestinal

c. Cardiovascular

d. Central Nervous System

and is normally considered in 3 temporal stages:

e. Prodroma, an initial toxic period

f. Latent period, or a period of relative well being

g. Manifest disease, when the major radiobiological damage to the organ systems becomes manifest.

Data on the acute radiation syndrome is somewhat limited. Peacetime experience of significant radiation exposure in humans is less than 100 documented cases; wartime cases suffer from inadequate and incomplete documentation, for which interpretation is contentious. However, certain generalisations can be made:

a. severity of the syndrome correlates with trunk exposure due to presence there of the majority of the gastrointestinal haematopoietic and cardiovascular systems.

b. single short exposure is more damaging than divided or multiple exposures (for the same total dose).

c. therapy can make a marked difference to outcome; whole body LD_{50} for minimal treatment in about 350 rads, with conventional hospital treatment about 500 rads and with heroic measures, e.g. marrow transplant, maybe in excess of 1000 rads.

The time-course of the Acute Radiation Syndrome deserves examination in the context of "emergency treatment". This is shown graphically in figures 1 and 2 and further described in Table 2. From these it will be seen that emergency nuclear radiation casualties will be then suffering from:

a. Prodromal symptoms

b. Central Nervous/cardiovascular manifest illness

c. Possibly Gastrointestinal manifest illness.

Most casualties with manifest gastrointestinal illness, and the manifest haematopoietic illness will not present with those symptoms until 1 - 2 weeks after exposure and in that sense may not be considered "emergency" casualties.

The dose received determines the nature of illness produced. Clinical effects are produced by the following doses:

a. Prodromal symptoms > 50 rem

b. Haematopoietic symptom >200 rem
(dose dependent changes in the circulating blood picture can be detected in the laboratory for doses zero to 200 rem)

c. Gastrointestinal symptoms > 500 rem

d. Cardiovascular and Central Nervous symptoms >2000 rem

Hence, emergency casualties will be generated by exposures over the whole of the dose range. However, the relationship of symptoms and dose is too varied to permit anything but broad estimates of dose to be made from clinical assessment.

The Prodrome

This is the initial toxic period beginning within minutes to hours of exposure, depending on dose. It is probably due to acute radionecrosis with release of histamines, bradykeinin and other vaso active substances, with acute circulatory effects secondary to this release.

Symptoms will include nausea, vomiting, anorexia, sometimes diarrhoea, headache, malaise and a warmth sensation of the skin with itching and erythema. These symptoms are associated with a significant performance decrement but otherwise are not of serious magnitude from a clinical viewpoint. As well, in the high dose range (> 2000 rem) the entity of Early Transient Incapacitation (ETI) may be seen as part of the developing CNS/CVS syndrome.

Casualties can be expected to present with prodromal symptoms about 6 hours after exposure, although earlier presentation 2 hours after detonation will occur with higher doses of the order of 200 rems. In cases with less than 400 rems dose, symptoms will regress by 48 hours, or several days with higher doses. It is important (and difficult) to distinguish a true prodroma from the casualties psychological reaction to exposure, or the possibility of exposure.

Figure 1. Mean Survival Time (MST) with increasing radiation dose.

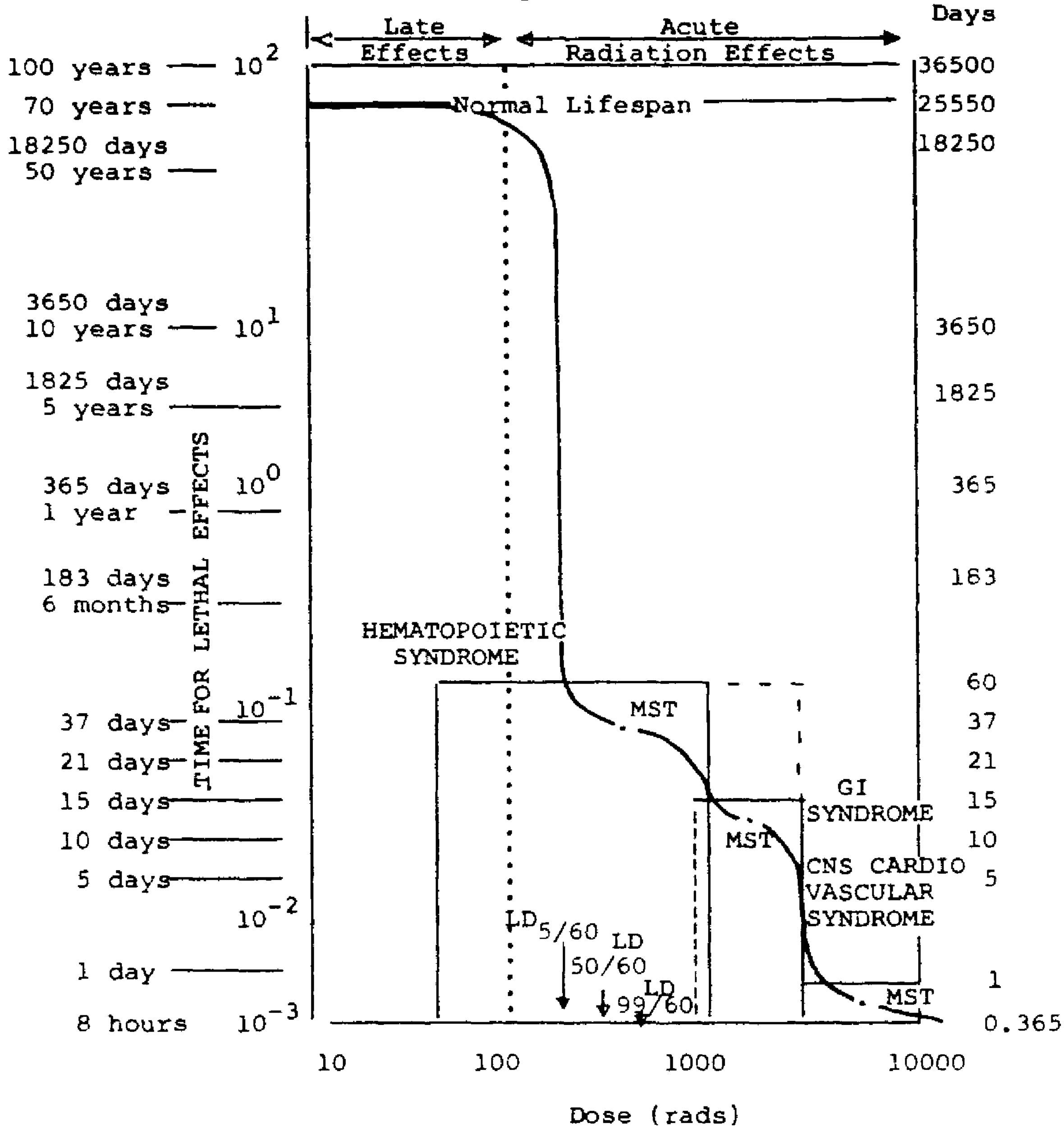


Figure 2. The Acute Radiation Syndrome:
Time sequence of the main events according to dose.

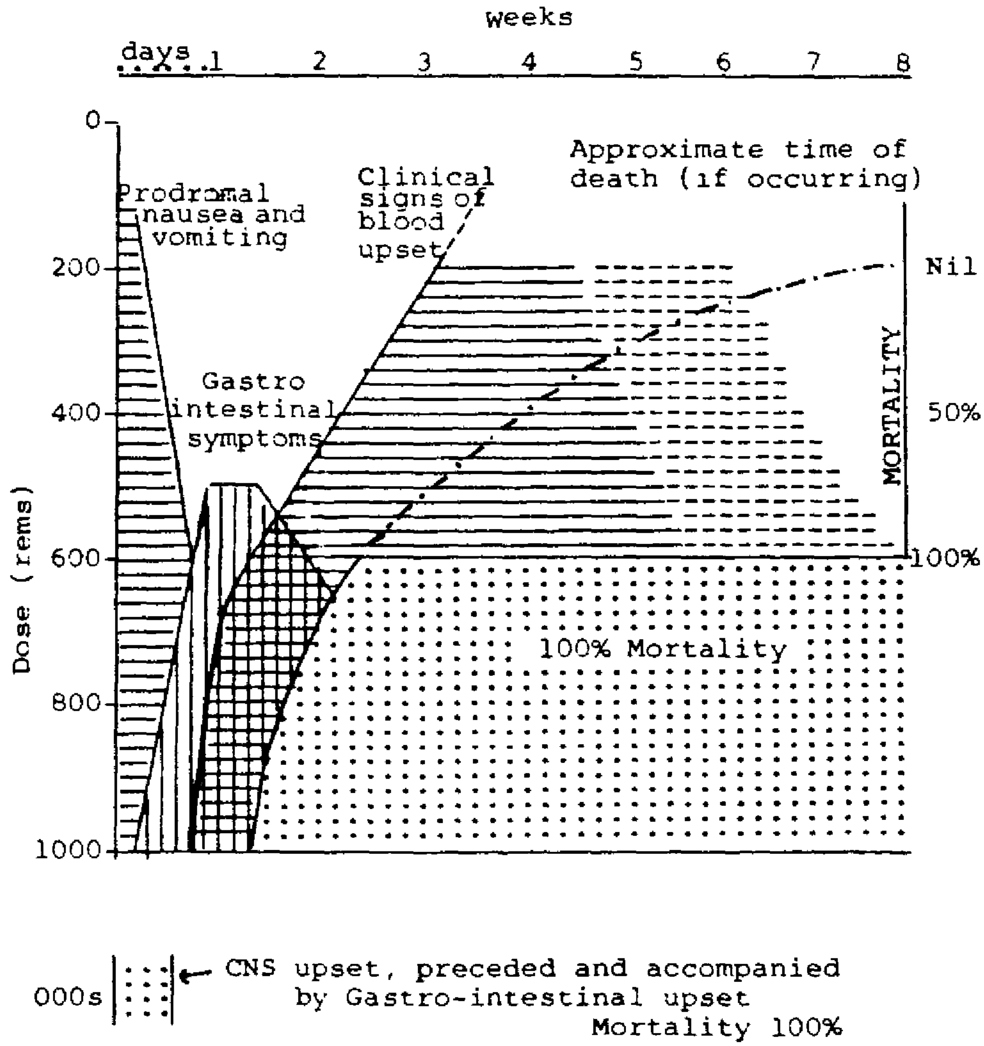


TABLE 2 -

Dose (rems)	1 hour	2-6 hours	6-8 hours	24-48 hours	
50 - 150		?	Symptoms reach maximum	Prodromal Symptoms subside	Latent Period ..
200-400		ø Nausea, vomiting			
*					
400 - 600		ø Nausea, vomiting		Symptoms may continue for several days ...	
600-1400	ø Nausea, vomiting Diarrhoea			... and may merge into Manifest Illness	
000s	ø Vomiting, Diarrhoea, Shock, C.N.S. impairment. Death within hours.				

* Double horizontal line is drawn at the LD_{50} level.

ø Onset of symptoms.

The Acute Radiation Syndrome: The prodromal phase, onset and duration of symptoms according to dose received.

Weeks 1 2 3 4	Presenting Type of Illness	Treatment required from	Outcome	Dose (rems)
....	Little clinical upset Perhaps only laboratory evidence of blood upset	?	Recovery likely	50-150
2 - 3 weeks	Clinical and Laboratory evidence of blood upset	3rd-4th week	50% or more recover	200-400
L.P. 1 - 2 weeks	Severe clinical evidence of blood upset. Gastro-intestinal upset at higher doses	2nd week	50% or more die	400-600
L.P. 0-7 days	Severe gastro-intestinal upset. At lower doses patient may survive long enough to show severe blood upset later	1st week	Death likely	600-1400
Patient already dead				000s

The Acute Radiation Syndrome: Duration of the latent period and presenting type of the manifest illness according to dose received.

Latent Period

Except where large doses cause the immediate development of CVS/CNS or GIT illness, a period of relative well being will follow regression of the prodroma. If the dose was less than 400 rems the latent period will last 2 - 3 weeks. If greater than 600 rems the prodromal symptoms will merge, developing into the GIT illness.

Manifest Illness

This phase is the result of changes in organ systems that begin at the time of exposure, but require time to become clinically apparent.

Skin. Epilation occurs at about 3 weeks. Extent and permanence are dose dependent, with no regrowth occurring with doses greater than 750 rems. Other skin changes range from desquamation and pigmentation similar to 1^{o} thermal injury at doses about 100 rems and changes similar to 2^{o} and 3^{o} thermal injury at doses of 1000 and 2000 rems respectively. Effects are due to direct radio-toxicity to epidermal cells and secondary to damage to skin vasculature. The skin changes are not likely to require consideration in emergency treatment procedures.

Haematopoietic System. Radiation causes a pancytopenia, effects becoming apparent in a time pattern consistent with the natural life span of individual blood cells. The clinical features do not emerge until weeks 3 - 4, although some laboratory changes may be detected earlier. Hence the haematopoietic casualties are not likely to require consideration in emergency treatment procedures. In general, atrophy and aplasia of the haematopoietic tissues, i.e. bone marrow, lymph nodes and spleen occur with consequent effects on the circulating cells. These effects are shown in figure 3.

Depression of circulating lymphocytes however occurs as an early response in the first 48 hours and is dose depenent at doses below 200 rem. The T-lymphocytes are relatively unaffected, whereas the B-lymphocytes decline. This is significant in that post-irradiation vaccination programs will be compromised.

Decreases in platelets and red blood cells also occur but unless haemorrhage (due to the GIT illness or other injury) occurs, anaemia is a late and relatively insignificant event. With doses greater than 600 rem antibodies decrease.

Gastrointestinal System. Effects are produced mainly in the small intestine, where the epithelium is almost as radiosensitive as the bone marrow, although other parts of the GIT are sensitive to larger doses. The pathology is primarily a result of death or inhibition of the proliferating cells in the crypts of the GIT epithelium; secondarily necrosis of mature epithelial cells and effects due to damage to epithelial microvasculature also occur. The villi lose epithelium, resulting in fluid electrolytes and blood loss into the GIT lumen, malabsorption, and entrance of bacteria from the lumen into the tissues and blood stream. Regeneration of epithelium starts after about 6 days and proceeds rapidly if exposure to less than 1300 rem occurred; with higher doses regeneration, if present, is slow and poor. Symptoms develop after doses in excess of 500 rem. Casualties show symptoms of nausea, severe vomiting and diarrhoea with watery and bloody stools, fluid and electrolyte loss, circulatory and renal failure. GIT and systemic infection initially due to the local pathology is aggravated by the developing pancytopenia due to haematopoietic damage. Death occurs between one and two weeks after exposure. Emergency treatment will be required for casualties receiving doses greater than 600 rem in the first week and doses in the range 500 - 600 in the second week.

Cardiovascular and Central Nervous Systems. Profound effects on these systems occur with doses greater than 2000 rem where ultimate survival is negligible. Some effects may manifest at lower doses and certain cardiovascular effects underlying effects in other systems have been mentioned in preceding paragraphs. The major significance of casualties with features of radiation injury to CVS and CNS is that they will form the bulk of early casualties for whom major and difficult decisions concerning manpower effectiveness, deployment and medical management will be required.

Pathology in these systems is complex. Doses 200 - 10,000 rem cause a general increase in vascular permeability with considerable loss of fluid into the extravascular space. Cellular radionecrosis and release of vasoactive substances, including histamine, polypeptides and bradykinin, and neurogenic amines capable of crossing the disturbed blood brain barrier, cause vaso-dilation by peripheral and central action, a fall in peripheral resistance and perfusion, leading to cardiovascular collapse. Death comes from shock within hours to days. With higher doses, greater than 10,000 rem effects in man are extrapolated from "animal work". Here direct damage to the CNS occurs with neuronal cell dysfunction, death, cerebral odema, and a rapid deterioration with death in minutes to hours. CNS dysfunction due to decreased perfusion, neuro active substances also occurs.

Symptoms. Initially are those of the prodrome, with severe vomiting and nausea, explosive diarrhoea occurring within minutes to hours. There is malaise, weakness, leading on to coma, shock and death.

Early Transient Incapacitation. This entity warrants separate consideration. Although the consequences in a casualty of vomiting and hypotension include effects on performance, the changes in performance are not entirely a result of those features. The entity is important as it will provide a proportion of early casualties for emergency treatment, and significantly affect the manpower effectiveness of personnel exposed.

Data is largely derived from animal irradiation. However, the 1958 Los Alamos accident in which an operator

Figure 3.a. The Acute Radiation Syndrome: Blood counts of four hypothetical patients exposed to doses of mixed gamma and neutron radiation. Doses are given as dose equivalents (rems) at top of each graph.

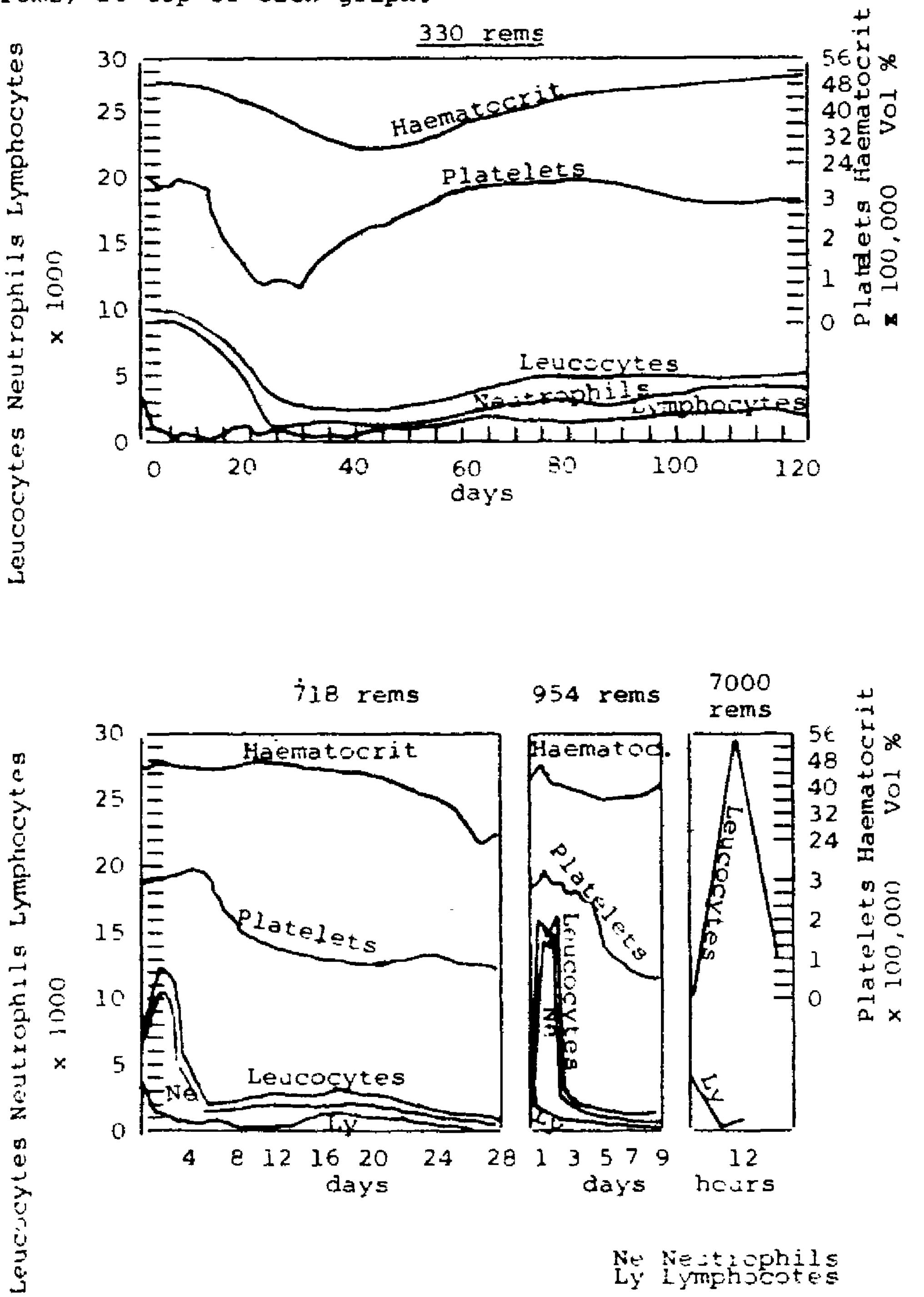
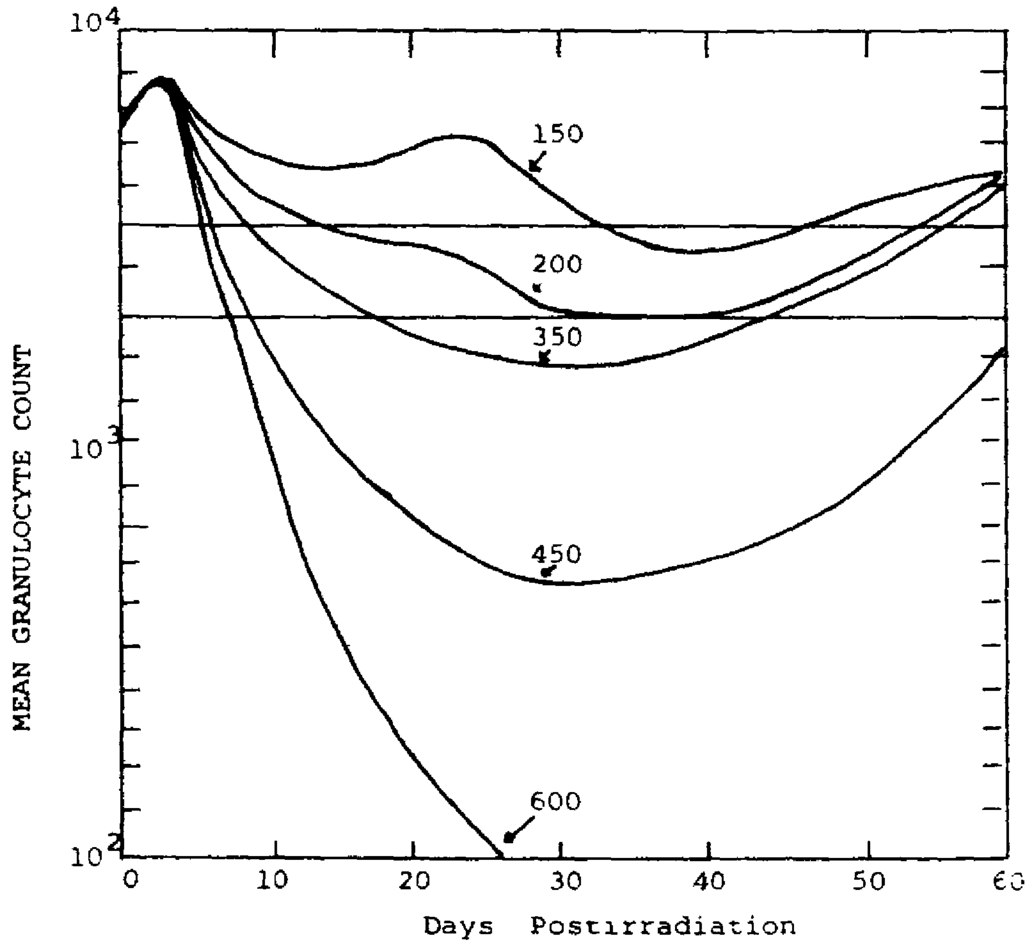


Figure 3.b. Circulatory granulocyte count in man/days post-irradiation.



Dose	% Mortality
150	0
200	5-10 Fever, infection
350	50 Fever, infection
450	85 Fever, infection
600	100 Fever, infection

was exposed to a mixed gamma/neutron irradiation of 4500 rad whole body (estimated 10,000 rad to front of head) illustrates the probable human syndrome. Immediately after the accident this casualty was able to complete his emergency exit drills satisfactorily, within minutes he became incoherent, ataxic and incapacitated, but 90 minutes later had recovered to a coherent state.

A similar picture is seen in monkeys irradiated and assessed in their performance of physical and behavioural tasks for which they have been trained. An ED_{50} (dose causing incapacitation in 50% of animals investigated) in the monkey has been determined for mixed neutron/gamma irradiation at 1600 rads.

Emergency - Triage and Immediate Procedures

In the immediate period after a nuclear weapons explosion, emergency treatment and casualty management will be determined mostly by the blast and thermal effects of the explosion. Emergency treatment delivered for all injuries will be a result of these effects on the number and type of casualties, on one hand, and the available medical resources, on the other. That is, the application of the principles of TRIAGE will be necessary.

For the emergency management of radiation injury due to causes other than nuclear weapons explosions, it is unlikely that either medical resources will be significantly compromised or casualty numbers will be high, so that routine medical procedures rather than triage will probably be required.

Other medical treatment procedures requiring consideration in the immediate post exposure period include radioactive decontamination, casualty dose estimation, and determination of medical stores requirement.

Triage

Triage is defined as the actions of assorting according to quality. This procedure will be invoked when there arises a disparity between the number of casualties and the facilities available to manage those casualties. Factors which require consideration are:

a. number of casualties

b. nature of casualties

c. condition of patients

d. facilities and resources available, both now and for the expected duration of the emergency

e. duration of travel from scene of sorting and assessment, to facility.

The critical factors are the balance between a. and d.

The process of triage is a continuing one. Ideally it commences at the site of the accident, permitting the most logical and orderly evacuation of casualties, most efficient use of transport, and optimum use of available first aid supplies. Triage continues at each rearward aid post or hospital up to the definitive treatment facility. As well, triage is chronologically an ongoing event, with casualties being reappraised after a period if retained in one facility, and re-sorted if their clinical state warrants this.

The control of triage is a most important and responsible duty. This must be undertaken by a medical officer, or the most senior paramedic present if no medical officer is available, which is likely at extreme forward casualty clearing stations. The triage medical officer must fulfil certain criteria. He should be a quite senior officer, so as to give authority and credibility to the difficult decisions of casualty sorting; as well he should be competent in surgery or critical care medicine. The triage team need only be small, as its primary function is sorting not treatment; however, as well as a clerical hand to record the triage details and any immediate treatments, the team should have one treatment hand to attend to any brief, life-saving treatments indicated as the team proceeds through casualty holding areas with its task of sorting casualties.

<u>Triage categories</u> are assigned to casualties by applying the fundamental objective of doing the greatest good for the greatest number of casualties. In a war zone and probably also in a civilian region devastated by a nuclear explosion, the element of expedience is added to that objective, so as to enhance combat force or community effectiveness in the shortest time. As a consequence there will be subtle but very significant differences in triage categories following a nuclear explosion, compared to those following a civilian accident such as an aircraft crash.

One good classification suitable for use with casualties which include radiation injury is:

a. Immediate treatment group

b. Delayed treatment group

c. Minimal treatment group

d. Expectant treatment group.

<u>Immediate treatment</u> group will be those casualties who can be treated with short, less than 30 minute duration, life saving procedures, following which an early return to duty or an effective role in the community is possible. Treatment must be possible by non-specialist general medical staff. Radiation injury would not normally warrant sorting into this group. (Example might be casualties with haemorrhage from an easily accessible site; a rapidly correctable mechanical defect such as a sucking chest wound; a traumatic amputation or severe crushing injury of extremities;

or an open fracture of a major bone. Note that this group does not include casualties traditionally given priority in a non-disaster setting, i.e. abdominal or chest wounds, as the length of time required to manage such injuries is a commitment contrary to the fundamental objectives of triage).

Delayed treatment group will be those casualties who can wait for treatment without loss of life, but with an increase in morbidity. Treatment can be managed by para medical personnel. Casualties held in the delayed group automatically move to immediate group after 2 hours. Radiation casualties with sub-lethal doses, with incapacitation would be sorted into this group. (Other examples might be moderate lacerations with need for pressure dressings, closed fractures of major bones, non-critical injuries of central nervous system, burns not more severe than 2^{o} between 20 and 40% body).

Minimal treatment group will be those who require little or no professional treatment, and can return to duty virtually immediately. Radiation casualties with sublethal doses without incapacitation would be sorted into this group. (Other examples include lacerations and contusions; simple small bone fractures; burns less than 2^{o} and 20%. Some may require domicillary "hospitalisation", such as psychoneurotic casualties; burns of hands and feet; disabling fractures of the small bones.)

Expectant treatment group will be those casualties who require an unacceptable commitment of time, personnel or medical supplies to manage. This group will be given supportive care until the workload permits a more intensive effort. Radiation casualties with lethal or supralethal doses would be sorted into this group. (Other examples include critical central nervous system or respiratory injuries; significant penetrating abdominal wounds; multiple severe injuries; burns more than 2^{o} and 40% body area).

Hence radiation injuries would undergo triage as follows:

Radiation Dose		Triage Group
Supralethal and lethal	-	Expectant
Sublethal with incapacitation	-	Delayed
Sublethal without incapacitation	-	Minimal

Radiation Casualty Dose estimation - Dosimetry

Estimation of radiation dose has a limited value in the determination of individual medical treatment and clinical prognosis. Primary concern must be with treating the patient as he presents and as the illness develops. The detection and repeated measurement of radioactive fields following a nuclear explosion will give important information affecting operation in those field situations. As well medical personnel must be trained in and equipped for the detection of patient contamination in order to prevent uncontrolled exposures of hospitals and personnel.