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AUSTRALIAN ATOMIC ENERGY COMMISSION

RESEARCH ESTABLISHMENT

LUCAS HEIGHTS RESEARCH LABORATORIES

THE LITTLE FOREST BURIAL GROUND — AN INFORMATION PAPER

by

Environmental Science Division

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1. INTRODUCTION

Burial in the ground is widely accepted by national and international authorities as a safe and practical way to dispose of solid radioactive waste[1]. Between 1960 and 1968 the Australian Atomic Energy Commission (AAEC) used an area at Little Forest near Lucas Heights for the disposal of waste with low concentrations of radioactivity that originated predominantly from its Research Establishment (RE) some 2 km to the southeast.

In the mid-fifties, when the AAEC was considering the need for a burial ground, other countries were using earth trenches to dispose of low level solid and liquid radioactive waste.[2]. Since the AAEC was then only just formulating the levels of liquid waste suitable for discharge to the Woronora River, it initially considered using the burial ground also for liquid waste disposal. The main purpose for the burial ground was as a disposal site for laboratory trash that could not categorically be classed as non-radioactive[3]. The limit on the annual dumping rate was to be 0.4 GBq (10 mCi). This rate should be compared with the deposition on the burial ground of 1.5 MBq (0.04 mCi) per year of strontium-90 alone[4] as atmospheric fallout from nuclear weapons testing.

Disposal of radioactive waste by burial is safe, provided that the return (called here exposure routes) of the radioactivity to food for human consumption, water, inhaled air or the external radiation environment is at a rate well within the limits recommended by international bodies as acceptable for members of the general public[5]. This safety is achieved by careful selection of burial ground sites[6].

Readers of this report may be assisted by referring to the glossary at Section 11.

2. SITING CRITERIA

Three broad sets of criteria are applied when selecting a site for a burial ground. These seek:

(i) to minimise the rate and the amount of radioactivity transported from the burial ground,

(ii) to maximise the amount of dispersion (dilution) that any transported waste will undergo before being in a position to expose members of the public, and

(iii) to provide convenience to the operator.

Characteristics of the first category are that a site should have no surface water, not be subject to flooding, and have a deep groundwater table with minimal seasonal and annual fluctuations. Preferred attributes in the second category include minimal present and predicted use of groundwater, low erosion rate, soil with a high absorptive capacity for metal ions, a deep bedrock, low groundwater velocities and a site physically isolated from people. The characteristics that make a site convenient for day-to-day operations include good access and service, closeness to the source of the waste, ease of excavation, no major landuse competition (e.g. mineral deposits), and government ownership.

In the fifties and sixties, more importance was placed on the last two categories; these days the highest rank is given to the characteristics in the first category[6].

Wastes disposed of by burial are not readily retrievable. Assurance of the safety of a burial site must stem from predictive computer modelling of its expected performance. Transport of contaminants by groundwater is a very complex process and, for there to be confidence in the computer modelling of it, the hydrogeologic characteristics of the site must be well understood and preferably very simple. This is now regarded as the most important siting criterion and is the one where the Little Forest area compares unfavourably with recently selected burial sites. Older sites in the UK and USA are also inferior in such comparisons and some, for example Maxy Flats, USA, have performed badly in comparison with the Little Forest site.

3. CHARACTERISTICS OF THE LITTLE FOREST BURIAL GROUND

3.1 The Site

The burial ground (see Figure 1) is located in a lens of Ashfield shale of the Wianamatta Group which overlies Hawkesbury sandstone. The shale lens is wedge-like, being thickest on the western boundary and thinnest to the east

of the AAEC-owned land. These shales are used commercially in the manufacture of decorative tiles and have been effectively worked out to the west. However, the NSW Department of Mineral Resources recently assessed the value of the shale to the east of the burial ground as non-commercial. The eastern extremity of the shale deposit was used by the Sutherland Shire Council for disposal of human excrement.

The combination of a shale lens overlying sandstone produces a perched aquifer. Hydrographs suggest that recharge of the perched aquifer is from precipitation over the burial ground with an effective runoff coefficient of 20 per cent and a soil porosity of 10 per cent (i.e. each millimetre of rain raises the perched water table 8 mm). Standing water levels suggest general groundwater movement to the north and west, a possibility of some movement to the east, but negligible flow to the south and south-west. This interpretation is in agreement with the advice received from the Under-Secretary, NSW Department of Mines in 1959 (following that department's involvement in site selection) that water from the shale-sandstone interface may emerge at the limits of the outcrop and enter Mill and Barden Creeks.

The groundwater is of adequate quality for industrial or domestic use but the limited potential yield of the perched aquifer makes both unlikely. As yet none has occurred and the proposed urbanisation of the region makes future use of the aquifer as a water resource even more unlikely.

Under sufficiently rainy conditions, the perched water table reaches the ground surface. Under such conditions, water that was originally underground can reach the surface and then flow over it. This characteristic was known at the time the site was selected and was one reason why the site was not used for the routine disposal of low level liquid radioactive waste.

3.2 Exposure Routes

Exposure routes are a consequence of the characteristics of the disposal site, and their significance is a consequence of the disposal operation. They fall into three general categories: two arise from transport of particulate and/or dissolved radioactivity by air and water respectively; the third is caused by the radiation field of the waste.

Water transport of radioactivity involving ground and/or surface flow can conceivably lead to contamination of

(i) drinking water,

(ii) crops from irrigated fields, and

(iii) marine food crops.

The fact that the headwaters of Mill and Barden Creeks have been used for the disposal of industrial and chemical wastes and human excreta rules out the first of these, and the ephemeral nature of the streams excludes the second. Furthermore, since the groundwater flow occurs predominantly at the shale/sandstone interface, it could not conceivably be the source of surface soil moisture through capillary action. Thus an unirrigated vegetable garden is not a potential exposure route. Radionuclides that are important for potential contamination of marine food products tend to be isotopes of elements with large bioaccumulation factors (e.g. zinc, copper, cobalt). The slow movement of the groundwater, and the fact that it is 15 years since the burial ground was used for disposal, limit the radionuclides of importance in the marine system to the longer-lived activation products, e.g. cobalt-60 (half-life : 5.3 years).

Another potential exposure route associated with water transport of contaminants is the external gamma radiation field that would result from bricks made from contaminated clay. This exposure route cannot develop quickly following burial operations since, on the one hand, contaminants that are not adsorbed on soil (e.g. tritium), and therefore move with velocities approaching that of the groundwater, will not contaminate the clay, whereas those that will contaminate the clay move much slower than the groundwater simply because they are adsorbed on soil. In practice, this exposure route can no longer develop at Little Forest as essentially all the clay has been mined, although a small amount is still taken for decorative tiles. This exposure route, were it to exist, would be quite limiting. About two thirds of the natural radiation background that people are exposed to arises from the building material used for their houses. Under international recommendations, the summation of all components of 'man-made' radiation must be less than about 40 per cent of this natural background. Thus, for the same mix of radionuclides, the allowable level of man-made contamination in brick clay is less than the natural levels.

Airborne contamination can arise only as a result of wind erosion of radioactive deposits at the ground surface. Surface contamination could

result from physical relocation of the waste (e.g. by intruders), by erosion of the cover material, or through initial groundwater transport where the change in chemical conditions at the surface causes the contaminants to be precipitated. As will be seen later, the airborne transport route requires special consideration at Little Forest because beryllium oxide was also buried there.

Provided that there are restrictions on the concentration of contaminants in air and surface waters, the radiation field resulting from ground contaminated as a secondary effect (e.g. as deposited dust) is of only minor importance. This exposure route is significant only if the waste becomes exposed through either physical upheaval or erosion of the cover, since the thickness of the cover is more than enough to shield the buried waste. Because of routine maintenance, the burial site is as safe as any parkland.

4. STANDARDS FOR THE EXPOSURE ROUTES

The policy of the AAEC is to comply with the most restrictive of the recommendations and/or regulations recommended by such international bodies as the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP), national bodies, such as the National Health and Medical Research Council (NH&MRC) and NSW State legislation, such as the Clean Waters Act and the Radioactive Substances Act. In summary, these requirements apply to the exposure routes as follows:

Medium	Origin of Standard
Surface water	NSW Clean Waters Act
Marine waters	IAEA/ICRP
Air - radioactivity	IAEA/ICRP
- beryllium oxide	NH&MRC
External radiation	ICRP

When applying the IAEA/ICRP recommendations, the limit on annual intake (ALI) by ingestion or inhalation is set at 1/100 of the ICRP recommended value of the ALI for occupational workers[7]. This factor takes into account age dependence in organ size, metabolism and radiosensitivity. It is further restrictively assumed that marine foods provide all the protein of the diet and that residents are continuously exposed to the prevailing atmospheric dust loading.

5. THE BURIAL OPERATIONS

Burial operations at Little Forest took place between 1960 and 1968. In all, 79 trenches were used for waste disposal (see Figure 2). Each trench was nominally 25 m long, 0.6 m wide and 3 m deep and spaced at intervals of 2.7 m. The waste was buried under 1 m of consolidated overburden but, because the trenching-waste disposal-refilling operation effectively raised the ground level, the thickness of overburden relative to original ground level was originally less than 1 m. Subsequent top dressing has increased this thickness.

The wastes buried consisted of solidified and solar-dried sludge from the liquid effluent treatment plant[8], trash from laboratories handling radioactive material (e.g. paper towelling, broken glassware, disposable pipettes), contaminated equipment (e.g. glove boxes), waste packages consigned by other organisations (e.g. universities, state government departments) and beryllium/beryllium oxide scrap.

The burial history is summarised in Table 1. The groupings I, II and III under 'Activity' are in descending order of radiotoxicity, based on drinking water standards. (The Appendix lists the radionuclides for each group.) These groups were taken from the IAEA recommendations of that time[9]. The fissile and fertile content of the waste was separately recorded, partly because of criticality considerations, and partly because of the auditing requirements on nuclear material. The AAEC's Waste Control Section received packaged waste from the originator who specified the type and quantity involved. These were believed to be generally overestimated. The only independent measurement available to the Waste Control Section was the radiation dose rate. On the basis of this measurement and the information supplied by the originator, the waste was categorised as either 'low', 'medium' or 'high' level waste. The appendix provides the operational definitions in vogue at that time. Note that there is no similarity between the definitions of 'medium' and high' in those days with those of today. For example, current usage limits the use of 'high' to waste originating from the processing of spent nuclear fuel that is heat producing. No wastes of this category are produced at Lucas Heights.

Beryllium was a special case. No restrictions were placed on the burial of solid waste contaminated with beryllium until mid-1967 when a limit of 5 g of dispersible beryllium per container of waste was imposed. Beryllium is not

radioactive but it can be toxic if inhaled as a sufficiently concentrated fine dust.

For the first three to four years of operation, there was an annual limit of 10 mCi (~ 0.4 GBq) on the waste that could be buried. By 1964, the procedure had been relaxed to one requiring a limitation of the surface dose rate per package of <5 mrad h^{-1} (50 μGy h^{-1}).

By 1967, the local definitions of 'low, medium and high' (see Appendix) were being applied so that the burial ground could be used for the routine disposal of 'low' and 'medium' level wastes. The disposal of 'high' level waste needed special assessment on a case-by-case basis.

During most years between 1960 and 1968, some liquid wastes were also dumped. In many cases these were non-radioactive (e.g. waste oil) or very weakly radioactive (e.g. liquid scintillants). The disposal of liquid waste peaked in 1966 at 3.1 m^3 (690 gallons).

The following standard containers were used for the disposal of

- sludge - metal drums (44 gallon)
- trash - sisalkraft bags
- equipment - fibreboard drums
- beryllium - fibreboard drums
- liquid waste - glass and plastic carboys.

Good records of the disposals were kept and copies are retained in operational AAEC files and the Commonwealth Archives and with the NSW Health Department. The end of each trench is marked; initially this was done with a numbered wooden pole, then each had a steel reinforced concrete pole; now the marking is done with a subsurface plate and surveyor's coordinates.

6. ENVIRONMENTAL SURVEILLANCE RESULTS

Since the results of the environmental surveillance program for Lucas Heights are published annually, they will not be summarised here. However, results are reported for detected contamination which is attributable to the burial operations at Little Forest. In some cases, critics have wrongly, but understandably, attributed other results to the Little Forest operation.

These too are discussed.

Cobalt-60 is an easily detectable and common contaminant in wastes originating from reactor operations; it is usually not present in detectable quantities in fallout from atmospheric nuclear weapons testing. As will be explained in Section 7, cobalt would normally become solubilised during the decaying phase of buried waste, and evidence based on overseas experience suggests that cobalt can travel in the colloidal form through soil without undergoing substantial absorption. For these reasons the presence of cobalt-60 is a sensitive and unambiguous indicator of leakage from buried waste.

In 1969, cobalt-60 was found at low concentrations (< 0.2 Bq L^{-1}) in bore water from bore OS3 (see Figure 3). Similar results for the same bore were found in 1970 and 1972. In 1970, cobalt-60 was also found in leaves of acacias growing over the buried waste (0.03 Bq g^{-1}). Similar results, expressed in the same units, were also obtained in

1971	0.07	1975	0.02	1979	0.004
1972	0.06	1976	0.06	1980	0.004
1973	0.14	1977	0.04	1982	0.0004
1974	0.03	1978	0.004		

In 1971 cobalt-60 was present in grasses growing over the burial trenches (0.4 Bq/g). Similar results, expressed in the same units, were obtained in

1972	0.3	1975	0.06	1978	0.003
1973	0.3	1976	0.07	1982	0.001
1974	0.2	1977	0.2		

Strontium-90 is a common constituent of wastes from reactors and is relatively mobile via groundwater transport through soil. Strontium-90 is also present in fallout from atmospheric nuclear weapons testing programs. In the Lucas Heights environs, the strontium-90 levels have always been consistent with levels found and recorded elsewhere in Australia as a result of fallout. Thus, any strontium-90 levels in samples from the Little Forest area which are significantly greater than those taken from elsewhere can be attributed to burial operations. However, cobalt-60 will also be present for the reasons given above.

Since 1973, samples of surface soils collected from over the burial trenches have been analysed. The highest levels recorded, in units of Bq g^{-1} for cobalt-60 were

1973	1.3	1975	3.0	1977	2.8
1974	0.3	1976	7.5	1978	1.9

When analysed for strontium-90, these samples also indicated its presence at about one-third of the cobalt-60 concentration, and it is attributable to the burial operations. Consequently the area was top-dressed in 1979.

By 1974, it was clear that some activity was being transferred from the buried waste to the overlying soil. This was occurring in two groups of trenches — 68-71 and 55-58. For the first group, the evidence came from the levels of cobalt-60 and strontium-90. For the second,the evidence was gross alpha activity levels which subsequent analyses showed to arise predominantly from plutonium 239/240 and the daughter product of plutonium-241, americium-241. These levels were associated with quite visible iron stains of very limited extent, for reasons that will be advanced in Section 7. The highest gross alpha activities (in units of Bq g^{-1}) recorded were

1974	22.4	1977	15.0
1975	12.2	1978	1.3
1976	16.3		

Tritium, as tritiated water, formed by the neutron bombardment of heavy water, undergoes no geochemical absorption processes and acts as a tracer of groundwater/surface water movement. Tritium was found in groundwater from many exploratory bores sunk within the fenced area of the burial ground during 1975-76. It was also found in water from the monitoring bores within the burial ground during the period 1978-1982 and at trace levels in the bore holes just north of the fenced area over the period 1978-1981. The detected concentrations were of no radiological importance; their value is as a tracer of groundwater movement from the burial trenches to the monitoring bores. The detected plumes lie in the north-east quadrant.

Trace quantities of zirconium-95 (half-life: 64 days) and its daughter product niobium-95 (half-life: 35 days) were found in bore water from OS3 in January 1971. Some critics have asserted that it was from the buried waste but this is not so; its origin was fallout. The French carried out eight nuclear tests in the atmosphere at Mururoa between May and August 1970. As a consequence, relatively high levels of beta/gamma activity were found in rain samples throughout the South Pacific basin and, in particular, relatively high levels of zirconium/niobium-95 were found in air at Tahiti during 1970-71 with yearly averages of $\sim$ 7 Bq m^{-3} [10]. Zirconium would not be present in groundwater from the burial trenches, partly because of its short half-life

(64 days) and partly because of its geochemical adsorption. In other words, this isotope was present because rainwater had directly entered the borehole which, at that time, was not adequately collared in order to prevent direct ingress of rainwater.

Radioactivity is very easy to detect at very low concentrations. Some people confuse the ease of detection with the significance of the result. A comparison with naturally occurring levels of radioactivity helps put monitoring results in perspective. The gross alpha activity of virgin soil depends on its uranium and thorium content and, in a sandstone region like Lucas Heights, is in the range 0.5-1.0 Bq g^{-1}. Similarly, the gross beta activity of seawater, and also of many groundwaters, is due predominantly to naturally occurring potassium-40. Seawater has a radioactivity content of $\sim$ 10 Bq L^{-1}.

7. PERFORMANCE OF THE LITTLE FOREST BURIAL GROUND

There are several aspects in the performance of the Little Forest burial ground that were probably not anticipated by either the site selectors or its users. The first is the detection of tritium in bore water from locations within and outside the fenced area[11]. This result would have been surprising for several reasons. The AAEC did not knowingly dispose of any significant quantity of tritium. It is therefore assumed that a waste consignment (e.g. liquid scintillant) originating from an external organisation, such as a university or a state government department, contained significant amounts of tritium. Further, the detection of tritium in bore water from the north-east corner at such an early date belies the discontinuity in groundwater chemistry at that site and the value(s) understood for groundwater velocity[11]. This observation can be explained by a combination of groundwater to surface and surface to groundwater flows during a drought-flood climatic regime. The initial groundwater flow would move the tritium through the zone of opposing surface and sandstone/shale interface contour gradients (see Figure 3). The fast surface flow would account for the relatively high average speed, and subsequent infiltration on the down-slope side of the geochemical discontinuity would be consistent with the hydrology of this area. In this respect it is worth noting that bore hole BHE (Figure 3) becomes artesian during wet seasons.

The second unexpected performance is that of the subsidence occurring within the burial trenches which was slow and limited in extent. The most significant subsidence became evident some 14 years after filling. Remembering that only minimally compactable waste was buried in metal (44 gallon) drums and that the biodegradable waste was packaged in degradable containers, this rate of subsidence is slower than that experienced in general landfill operations. Two explanations are offered. The organic liquids and solvents that were simultaneously disposed of may have suppressed, at least for some time, the soil microflora. Alternatively tunnel erosion could, to a degree, be occurring. The latter is the more insidious. There is no radiological evidence of it but future maintenance will take this possibility into account. The very localised major subsidence almost certainly coincides with buried cavities (e.g. glove boxes). Although good records were kept on the waste buried in each trench, none were kept on the distribution of this waste within a trench. It is therefore not possible to verify the above hypotheses on buried cavities.

Although some surface expression of the buried waste was expected, e.g. the cobalt-60 levels in acacia, grass and soil over the burial trenches, others were not. Plutonium is readily adsorbed on soil from groundwater in almost all geochemical environments and would be one of the last contaminants expected to be evident at the surface. The visible iron stains that were associated with the discrete samples that contained plutonium contamination provide an insight into the transport mechanism involved. The following facts are relevant:

- The trenches that contained most of the plutonium-contaminated wastes were also used for the disposal of liquid waste including organic solvents. Thus a mechanism of solubilising some plutonium existed.

- Decay of laboratory trash would produce a reducing environment (low redox potential) and acidic groundwater (low pH) rich in dissolved iron and manganese in an identical way to the regular performance of municipal landfill operations.

- At low pH and redox potential, plutonium is not immediately adsorbed on soil. Thus if the solution passed through only a short soil column before reaching the surface then plutonium would be detectable there.

. At the surface, the solution would be oxidised and neutralised, ferric hydroxide would precipitate and, in so doing, scavenge out the dissolved plutonium.

For this senario to be credible, all that is needed is a short path length through soil for the trench water. All cases in which visible iron staining was found originated at or close to the marker posts. It is assumed that when the posts that mark the end of each trench were driven in, some penetrated into the buried waste.

Another surprising feature is the lack of evidence of any movement of contaminants by groundwater, even to bore holes very close to the buried waste. Other than low levels of cobalt-60 in borehole OS3 for a 2-4 year period, no contaminants have been found. At the same time, the detection of tritium in many of them clearly demonstrates that the boreholes are suitably placed and adequately monitored. This means that, provided the flow path through soil is sufficient (a few metres) for neutralisation of the trench water to occur, then groundwater transport is of only minor interest. In this sense, the 'poor' characteristic of the burial ground, with respect to rainfall infiltration, is a safety factor since the acidity of the trench water is reduced by dilution.

8. ROUTINE MAINTENANCE

The regular maintenance of the burial ground consists of fence repair, mowing and top-dressing those areas showing signs of subsidence.

The only way that risk could develop from past burial operations would be by physically uplifting the buried waste. This could conceivably happen by illicit use of heavy machinery on the burial ground or by, say, 'off-road' vehicles running along the trenches during boggy conditions. Entrance of such vehicles is prevented by routine patrol and maintenance of the security fence.

The surface is mowed to reduce the chance of a grass fire on the burial ground. If the vegetation cover over the burial trenches were to be destroyed by fire, the erosion rate would become orders of magnitude higher.

Top-dressing corrects the results of subsidence. The best way to apply and consolidate the top-dressing depends greatly on the rate of subsidence.

The top-dressing is applied and lightly compacted under dry conditions, a procedure which corrects the subsidence but does little to climax its rate of occurrence. The use of vibrator plates to accelerate compaction effectively is being considered but, in the slightly longer term (~ 5 years), sterner measures could be applied.

Overseas research[12] has demonstrated that the most cost-effective way to compact burial trenches and so minimise further subsidence and substantially reduce rainfall infiltration is to use a falling mass in a way similar to that used for driving piles. Before using this method, there must be complete confidence that the weight will not penetrate to the buried waste and become entangled in a partly corroded waste container.

9. THE LONGER TERM ASPECTS

Current practice for shallow ground burial of radioactive waste is to limit virtually all of the activity to radionuclides having half-lives of 30 years or less. Longer-lived radionuclides are still disposed of but their concentrations are limited, in the USA for example, to 370 Bq g^{-1} (i.e. 0.2 μg g^{-1} for plutonium-239). These limitations regulate the period (to, say, 200 y) during which administrative control and routine maintenance must be exercised over the burial site.

The Little Forest burial ground cannot be viewed in this way because of the amount of beryllium oxide that is buried there in powder form. In this sense the site is more accurately equated to a toxic material disposal site as used for, say, asbestos waste. Asbestos waste is handled in New South Wales by ensuring that the dumped material is the first (i.e. the bottom) layer at a new working face of the landfill operation. Thus, depending on the particular working face, the buried asbestos may or may not be below original ground surface.

Exhumation of the materials buried at Little Forest and their transport for re-burial at another site is not an option at present because there is no alternative site. Should a national disposal site be developed, exhumation would be considered. In the process the cost-benefit of such action would have to be fully assessed, paying particular attention to its potential for the creation of a dispersion hazard during removal; such an assessment might favour leaving the waste in situ.

As a consequence, land use of the site should be assumed to require control in perpetuity. Under Section 55 of the NSW Public Health Act 1902, for example, the site could be declared unhealthy building land. This Act has been used for such a declaration over land in West Menai, viz portions 121, 122, 124, 125, 126, 254 and 255, because of past dumping in these lots of excreta, industrial waste and garbage.

In the longer term, risks to the general public could develop only if intruders were to dig up the waste or if the cover material eroded away. In the foreseeable future illicit entry will still be prevented by security measures.

The consequences of illicit activities by intruders could be dramatically reduced by preventative measures. In the last section it was foreshadowed that once the natural subsidence had climaxed (with a fill density about half the virgin value) mechanical compaction by the falling mass technique will be applied. This procedure will not only increase stability and reduce rainfall infiltration but also, because of the increased density, allow high pressure grouting of the burial trenches.

Grouting is a technique used to strengthen soils by injection of a cementing agent. Injection of a cement-sand slurry results in volumetric compaction of soils and, most importantly in the present context, it also effectively fills moderate size voids, such as those likely to be encountered between and within buried waste containers. Thus mechanical compaction combined with high pressure cement grouting would not only substantially reduce the chance of physical disturbance of the waste by intruders but also minimise the dispersibility of the waste if physically uplifted. It follows that if, at some future time when there is a national waste disposal site, the decision were taken to relocate the wastes buried at Little Forest, then physical compaction and grouting undertaken as in situ preventative measures would make mining and repackaging of the waste less onerous.

Significant erosion could come about through either 'tunnel' or long-term sheet erosion. Examples of tunnel erosion can be seen on country hillsides. It is frequently initiated by marked rainfall infiltration at the site of a large, burnt-out tree root system. The infiltrating rain erodes a tunnel through more erodable soil sub-strata which finally breaks out on the surface further down the hill. It can be prevented by either ensuring that there is a low gradient down-slope or that there are no sink holes. The current

maintenance program is aimed at the latter; the longer term strategy will address the former.

The shales of the burial ground site are geomorphically stable at a slope of 1:25 or less. The only region of the burial site that fails to meet this requirement is the perimeter of the burial trenches, particularly the eastern boundary of trenches 1-56. In the medium term this situation will be corrected by relocating the boundary fence. At that time it would be prudent to dispense with monitoring bore holes OS1, OS2, OS3 and BH10 since access to them would be parallel to the newly created contours. The area immediately to the east of the burial site was used for human excrement disposal. Compaction is still occurring and recontouring is best left until the area has stabilised.

Thus, although the burial ground in its present state constitutes no hazard, its integrity can be improved over time and its existence in no way limits the land-use options for the surrounding region.

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11. GLOSSARY

Acceptable (effective) dose (equivalent): An annual limit (for members of the general public) that weights the tissue being irradiated by its radiosensitivity to yield an effective (whole body equivalent) dose. The limit recommended by internatiional bodies as being acceptable for protracted exposure is calculated, under a set of conservative assumptions, to be equivalent to an annual risk of one in a million. Under the same set of assumptions the annual risk from natural background is over twice this value. Radon decay products are the major contributor. The SI unit of absorbed dose is the gray (1 joule per kilogram), the unit of dose equivalent is the sievert (Sv).

Aquifer: A soil or rock layer containing water in recoverable quantities. If the aquifer is underlain by impermeable strata then it is perched, i.e. hydrologically isolated.

becquerel (Bq): The SI unit for radioactive decay; 1 decay per second. Naturally occurring potassium has a radioactive content of about 0.3 Bq per gram.

Recharge (area): The geographical area where infiltration of rainwater recharges an aquifer. The recharge area must be hydrologically up-slope of the aquifer but can be geographically well separated.

Runoff coefficient: The fraction of incident rainfall that runs off (i.e. does not infiltrate or evaporate from) the catchment area.

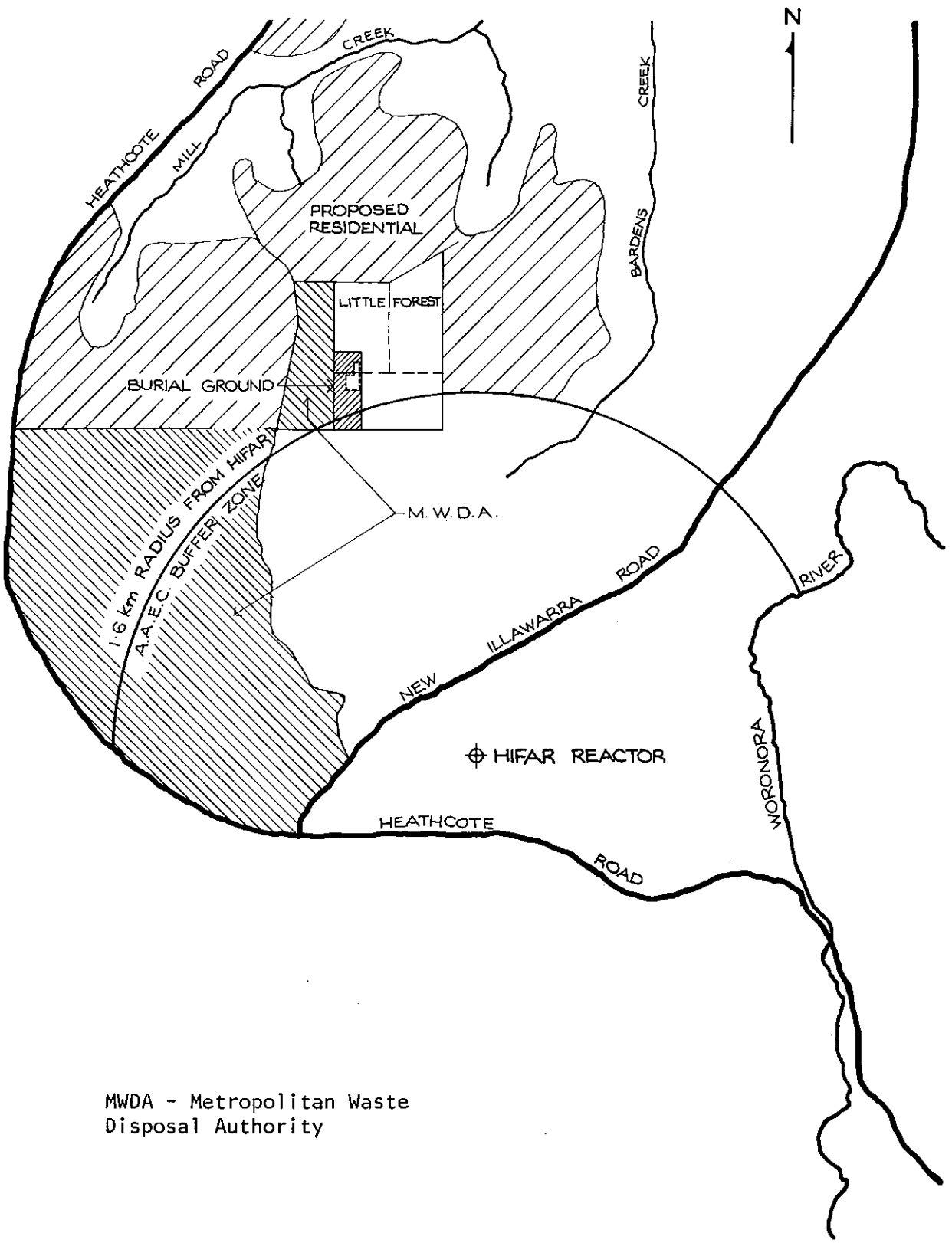
Scintillant (liquid): A liquid scintillator, often using toluene, in which the products of radioactive decay can be electronically counted through the light pulses given off when the radiation interacts with the scintillant. Frequently used in biomedical research.

Sorption processes: A term used to cover all the physical and physicochemical processes that lead to a movement of ions from water to the medium (e.g. soil) that is in contact with it. Sorption processes include adsorption, absorption and ion exchange and colloid filtration mechanisms; such processes may be reversible or irreversible. They cause the contaminant front to move much more slowly than the transporting groundwater.

TABLE 1
THE BURIAL HISTORY FOR THE LITTLE FOREST DISPOSAL SITE

Year	Trenches filled	Estimated activity (mCi)[a]			Fissile content (g)			Fertile content (kg)		Be/BeO content	Liquid volume
		I	II	III	Pu	U^3	U^5	U	Th	(kg)	(m^3)
1960	1-5	0	0.1	0	0	0	0	0	0	0	0
1961	6-18	1	3.9	3.8	0	0	5.3	0.3	2.3	89.8	1.54
1962	19-26	0	4.2	6.2	0	0	23.6	0	0	105.4	2.25
1963	27-36	0	4.0	5.6	0	0	0	0	0	139.2	0.34
1964	37-46	0	77.6	74.6	0	0	18.2	3.8	0	237.1	0.09
1965	47-53	0	14.7	26.2	1.98	2.31	8.9	4.3	18.6	151.4	0.59
1966	54-61	0	39.4	20.8	4.44	0.4	17.6	0.3	5.6	157.6	2.88
1967	62-70 +S1	0	310	429	0.46	2.5	15.0	47.1	13.4	185.1	0.89
1968	71-76 +S2	19.3	603	2447	0	0	3.41	3.45	8.17	3.8	0

(a) The groups I, II, III are in descending order of radiotoxicity, based on drinking water standards[9]. U^3 and U^5 refer to uranium-233 and -235 respectively.



MWDA - Metropolitan Waste Disposal Authority

FIGURE 1 LOCATION OF LITTLE FOREST BURIAL GROUND

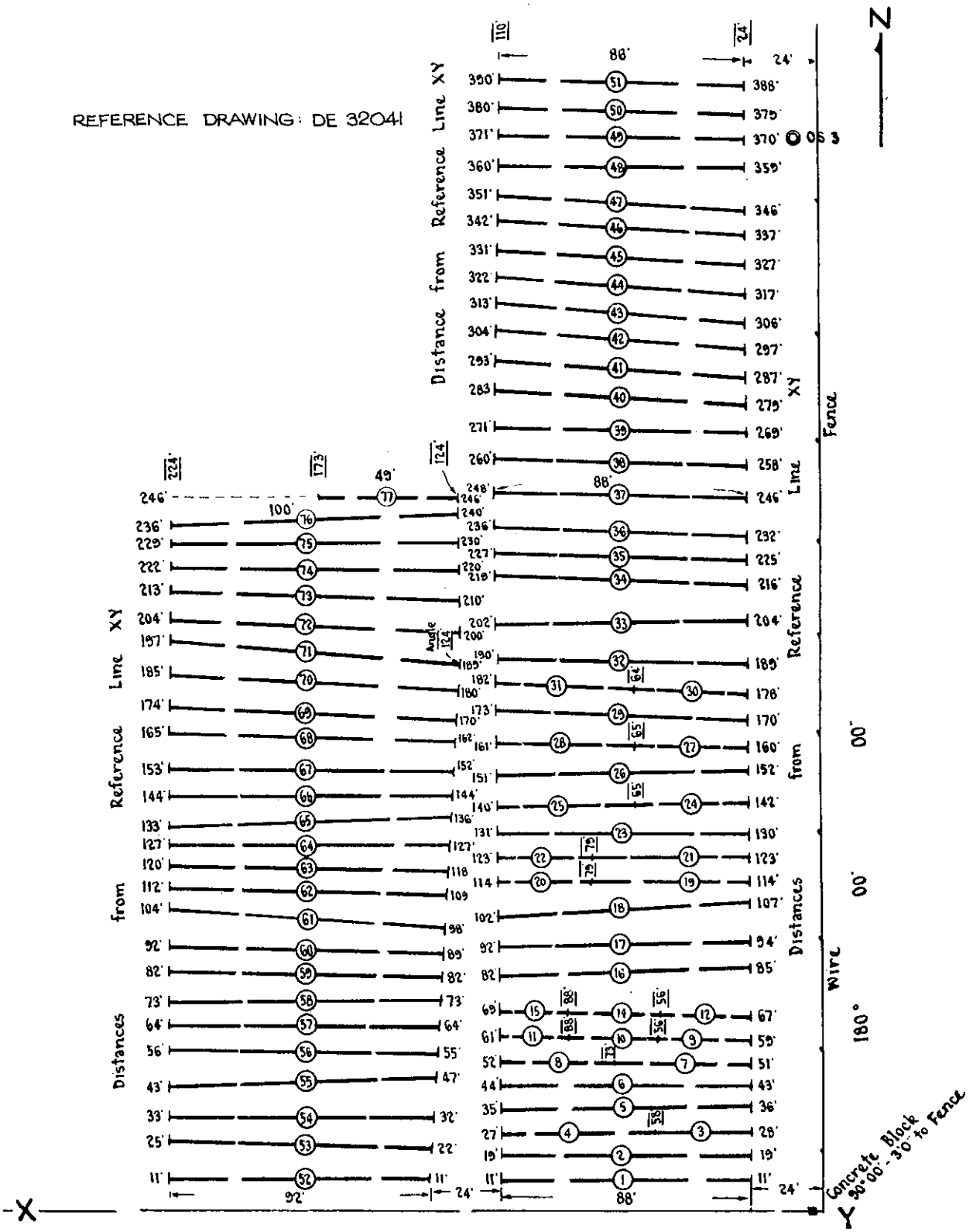


FIGURE 2 SURVEY OF TRENCHED AREA - LITTLE FOREST BURIAL GROUND

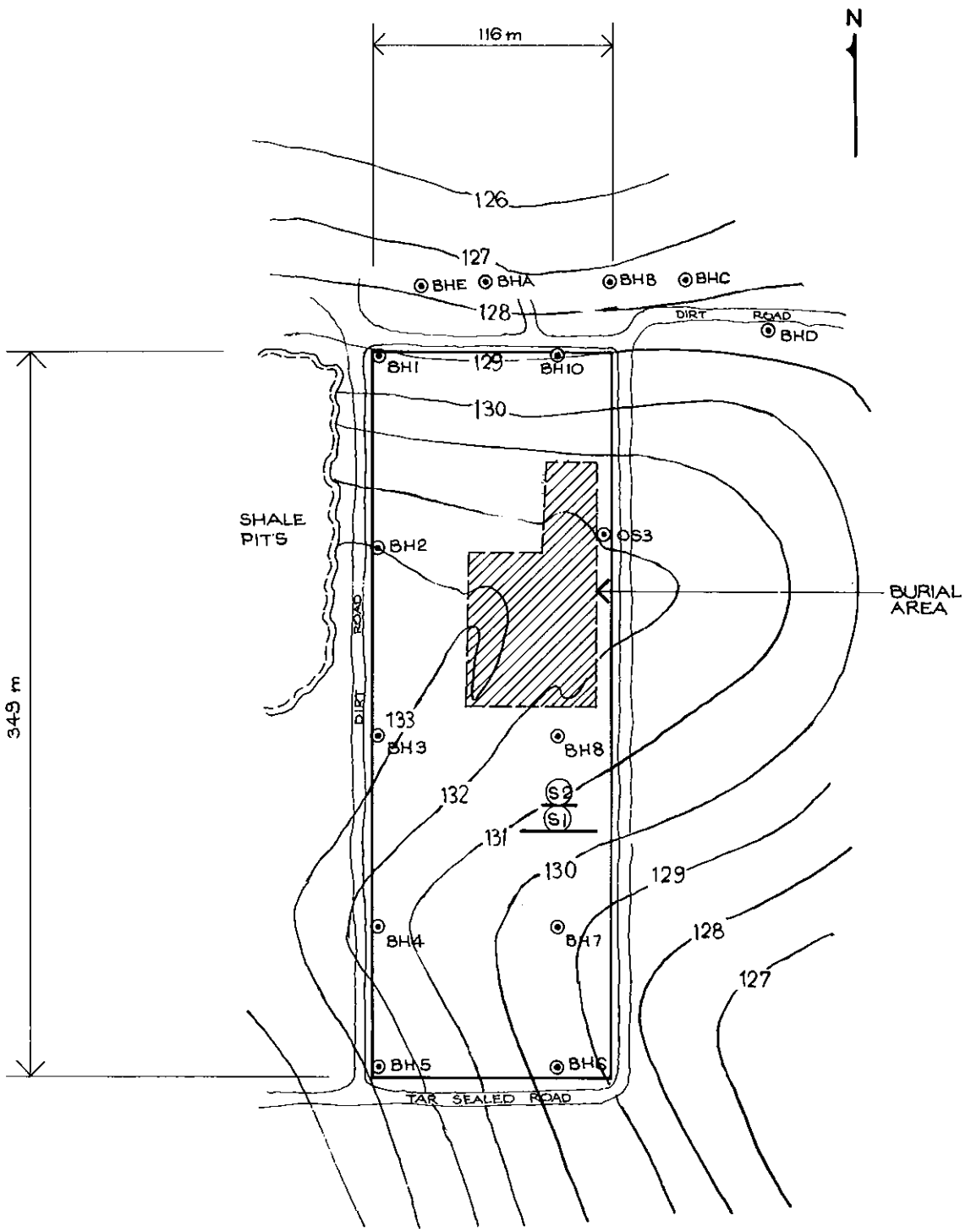


FIGURE 3 BURIAL GROUND SHOWING BURIAL AREA, LOCATION OF BOREHOLES AND SURFACE CONTOURS (IN METRES)

APPENDIX

EXTRACT FROM REFERENCE 1
OPERATIONAL DEFINITIONS OF CATEGORIES OF LOW, MEDIUM AND HIGH LEVEL SOLID WASTE[1]

1. Low Level Waste

Low level solid waste is so defined to permit routine collection and disposal of the waste. It includes all active area waste contaminated to levels below the following maximum activity per container.

Either 0.5 μCi* of Group I (see table below) radionuclides (includes 10 μg ^{239}Pu),

or 20 μCi of Group II radionuclides (includes 2 mg ^{233}U, and mixed fission products),

or 1 mCi of radionuclides of Group III and higher groups (excluding natural U, ^{235}U and natural Th),

or 150 mg of natural uranium, thorium or ^{235}U,

or 5 mg of beryllium (any form),

or 100 mg of other toxic material such as cyanides or mercury,

and surface dose rates should not exceed 2.5 mrem h^{-1}**.

If the mixture of the above is present, then the corresponding amounts must be reduced accordingly.

[1] Note that definitions low, medium and high level waste as given here bear no relationship to their present-day meanings; for example, high level waste today means the waste from processing spent nuclear fuel.

* 1 μCi = 37 kBq ** 1 rem = 0.01 Sv

Selection of radioactive nuclides taken from Regulations for the Safe Transport of Radioactive Materials (Revised Edition), IAEA, Vienna, 1967.

GROUP I

^{227}Ac, ^{241}Am, ^{237}Np, ^{230}Pa, ^{231}Pa, ^{210}Po, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{226}Ra, ^{228}Ra, ^{228}Th, ^{230}Th, ^{232}U

GROUP II

^{41}Ar, ^{210}Bi(RaE), ^{154}Eu, Mixed fission products, ^{233}Pa, ^{210}Pb, ^{223}Ra, ^{224}Ra, ^{222}Rn. ^{90}Sr, ^{233}U, ^{135}Xe

GROUP III

^{140}Ba, ^{144}Ce, ^{36}Cl, ^{60}Co, ^{131}I, ^{133}I, ^{114m}In, ^{192}Ir, ^{85}Kr, ^{106}Ru, ^{124}Sb. ^{125}Sb, ^{46}Sc, ^{89}Sr, Th-(nat), ^{204}Tl, ^{235}U, ^{238}U, U-(nat), ^{133}Xe, ^{91}Y, ^{95}Zr

2. Medium Level Waste

Medium level solid waste is defined so that it includes all waste which may be safely handled, transported, stored and disposed of with minimum precautions, and will not normally require shielding. However, any amount of short half-life isotopes ($T_{1/2}$ < 100 days) may be included in which case shielding to reduce the surface dose rate to 200 mrem h^{-1} is required during removal. It includes all waste known to contain more activity than low level, and less than the following maximum activity per container.

Either 0.5 mCi of Group I radionuclides (includes 10 mg ^{239}Pu),

or 20 mCi of Group II radionuclides (includes 2 g ^{233}U and mixed fission products),

or 1 Ci of radionuclides of Group III and higher groups (excluding natural U, ^{235}U and natural Th),

or 150 g of soluble natural U, depeleted U or natural Th,

or 2 kg of insoluble natural U, depleted U or natural Th,

or 10 g of ^{235}U,

or 5 g of dispersable beryllium (any form),

and any quantity of massive Be metal or sintered BeO,

and 100 g of other toxic material such as cyanides or mercury.

and surface dose rates must not exceed 200 mrem h^{-1} on the outside of the primary container (no limit on dose rate if $T_{1/2}$ < 100 days). If mixtures of the above are present then the amount of each must be reduced accordingly.

3. High Level Waste

High level solid waste includes all solid waste which exceeds any of the limits laid down for the medium level category. It does not include short half-life material ($T_{1/2}$ < 100 days) which is classified as medium level waste.