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Background Report on the Little Forest Burial Ground Legacy Waste Site

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Australian Nuclear Science and Technology Organisation

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Summary

The Australian Atomic Energy Commission (AAEC) buried low-level radioactive waste at the Little Forest Burial Ground (LFBG) near Lucas Heights between 1960 and 1968. The disposal site has since been under a constant care, maintenance and routine monitoring regime by the AAEC and its successor, the Australian Nuclear Science and Technology Organisation (ANSTO). The routine environmental measurements at the site have been reported in ANSTO's series of monitoring reports.

ANSTO has commenced a detailed scientific study of the status of the site, including sampling of vegetation, groundwater and soils. The project has undertaken soil coring, geophysical surveys and installation of groundwater sampling bores. The research applies advanced analytical techniques, such as accelerator mass spectrometry, which have not been employed in the analysis of environmental samples from the LFBG in the past. Project personnel are reviewing documents related to the disposal operations, as well as information and data from over 40 years of monitoring and investigation of the LFBG. In addition to relatively short-lived radionuclides, such as ^{60}Co, ^{137}Cs and ^{90}Sr, the site contains both non-radioactive toxic contaminants (including more than 1000 kg of beryllium) and long-lived alpha-emitting radionuclides including plutonium, uranium and thorium. Over the period since operations ceased, a plume of tritium in groundwater has developed and there has been intermittent subsidence of the soil covering the trenches. This subsidence is attributed to voids developing in the buried wastes, due to deterioration of containers and disposed objects. Contamination of the ground surface with radionuclides has been documented in some AAEC reports.

The data obtained by the research project at LFBG will enable the assessment of possible management options including continuing the current regime of maintenance and monitoring, in-situ remediation, or exhumation. Unless the site is remediated, it will require some form of institutional control in perpetuity, due to the presence of beryllium and long-lived actinides. The present report provides an overview of the disposal operations at LFBG, briefly reviews previous reports and describes current ANSTO research activities at the site.

Acknowledgements

The author has based this summary report on information obtained by ANSTO staff in various groups, including Environmental Monitoring, Waste Operations, ANSTO Records, and the Institute for Environmental Research (IER). The contribution of ANSTO staff is greatly appreciated.

The current research at LFBG is being implemented by personnel of the Contaminant Science Task within IER (Nuclear Methods in Earth Systems Project). The staff members currently involved are: Dioni Cendon, Eve Chong, Josick Comarmond, Matthew Dore, Stuart Hankin, Jennifer Harrison, Cath Hughes, Mathew Johansen, Lida Mokhber-Shahin, Tim Payne, Brett Rowling, Sangeeth Thiruvoth, Kerry Wilsher, and Henri Wong. Eve Chong is thanked for extensive efforts with the disposal records. Dr Mathew Johansen provided a comprehensive review of this document.

Related reports

J. Twining, J. Harrison, M. Vine, N. Creighton, B. Neklapilova and E. Hoffmann (2009). Analytical Method. Development for Tritium in Tree Transpirate from the Little Forest Burial Ground [ANSTO report NMESP/TN1].

S. Hankin (in preparation, 2012). Little Forest Burial Ground – Geology, Geophysics and Monitoring Wells [Report No. ANSTO / E-781].

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Introduction

From 1960 to 1968, the former Australian Atomic Energy Commission (AAEC) disposed of radioactive waste in trenches at Little Forest, near its research facility on the southern periphery of Sydney. The contents of the trenches included radionuclides from the operation of the research facility, waste drums, chemicals, disused equipment, laboratory trash and beryllium-contaminated items. The waste was disposed of in a series of trenches, following the international practices which were used at that time for the disposal of low-level solid and liquid wastes. The disposal site, known as the Little Forest Burial Ground (LFBG), is situated at the northern extremity of the 1.6 km radius Buffer Zone around the former HIFAR Research Reactor at Lucas Heights. The successor to the AAEC, the Australian Nuclear Science and Technology Organisation (ANSTO) controls and manages the site. Since the cessation of disposal operations, the AAEC/ANSTO has undertaken continuous care, maintenance, surveillance and monitoring activities at the LFBG.

This report provides an overview of existing information about the LFBG, including operational records, monitoring data and previous reports. In addition it will introduce present ANSTO research activities at the LFBG, which will ultimately assist in determining the best options for management of the site.

Site description

The LFBG is situated inside the ANSTO Buffer Zone. It occupies a section of land where the buffer zone juts out from the 1.6 km radius circle around the former HIFAR reactor at Lucas Heights (Figure 1). The nearest residential area to the LFBG is the suburb of Barden Ridge, located 2.5 km to the east. The western parts of the suburb of Menai are about 3 km northeast of the LFBG. A proposal involving suburban expansion and other developments in the general area surrounding the LFBG is presently under consideration.

The LFBG site consisted originally of a rectangular area approximately 350 m long and 115 m wide surrounded by a cyclone wire fence, which on the eastern side was close to the trenches. In 1990, the eastern boundary line was re-positioned some 35 m to the east for about 260 m of its length from the northern end (see figure 2).

The site was cleared of its original native shale forest vegetation and is now covered predominantly by grass, which is mown on a regular basis. The site slopes gently to the north and to the southeast, with a surface drainage line developed towards the south-eastern corner of the site. Two adjacent sets of trenches containing the wastes are located on the higher part of the site. In addition, two trenches (S1 and S2) are positioned about 50 metres to the south of the main trenched areas (Figure 2). The trenches were filled in a sequential order as shown in Figure 3. The trenches were nominally 25 m long, 0.6 m wide and 3 m deep, and spaced 2.7 m apart. The waste was covered by about 1 m of the local clay soil. Records were kept of the disposal operations (discussed below), and these records provide an indication of the materials disposed in each trench.

The LFBG is adjacent on three sides to other waste disposal sites. On the western boundary is a former municipal waste disposal site known as Harrington's quarry. To the west of this site is the Lucas Heights Waste Management Centre, which currently includes a major municipal landfill operation. Immediately to the east of the LFBG is an area formerly used by the Sutherland Shire Council to dispose of night soil (human excreta). To the north-west of the LFBG lies a former industrial liquid waste site used for the disposal of grease, paints, solvents, tannery wastes, etc, as well as specific hazardous industrial chemicals including dioxin-contaminated materials and residues from herbicide production (Coffey Partners, 1991).

Climate and geology

The LFBG area has a warm temperate climate, with temperatures reaching their peak during February (when the average maximum temperature is 25.9˚C and minimum is 17.4˚C). The coldest month is July, with maximum and minimum of 15.7˚C to 7.1˚C respectively (Isaacs and Mears, 1977; Clark, 1996 and 2004). Mean annual rainfall at Lucas Heights was 1015 mm for the period 1958–2011 (BOM, 2011). Monthly average rainfall varies between 52.7 mm in September and 116.9 mm in March and the annual average pan evaporation is ~1200 mm. Alternating dry and wet periods are common, and can be prolonged as they are linked to wider climatic events such as El Niño and La Niña (Ummenhofer et al., 2009).

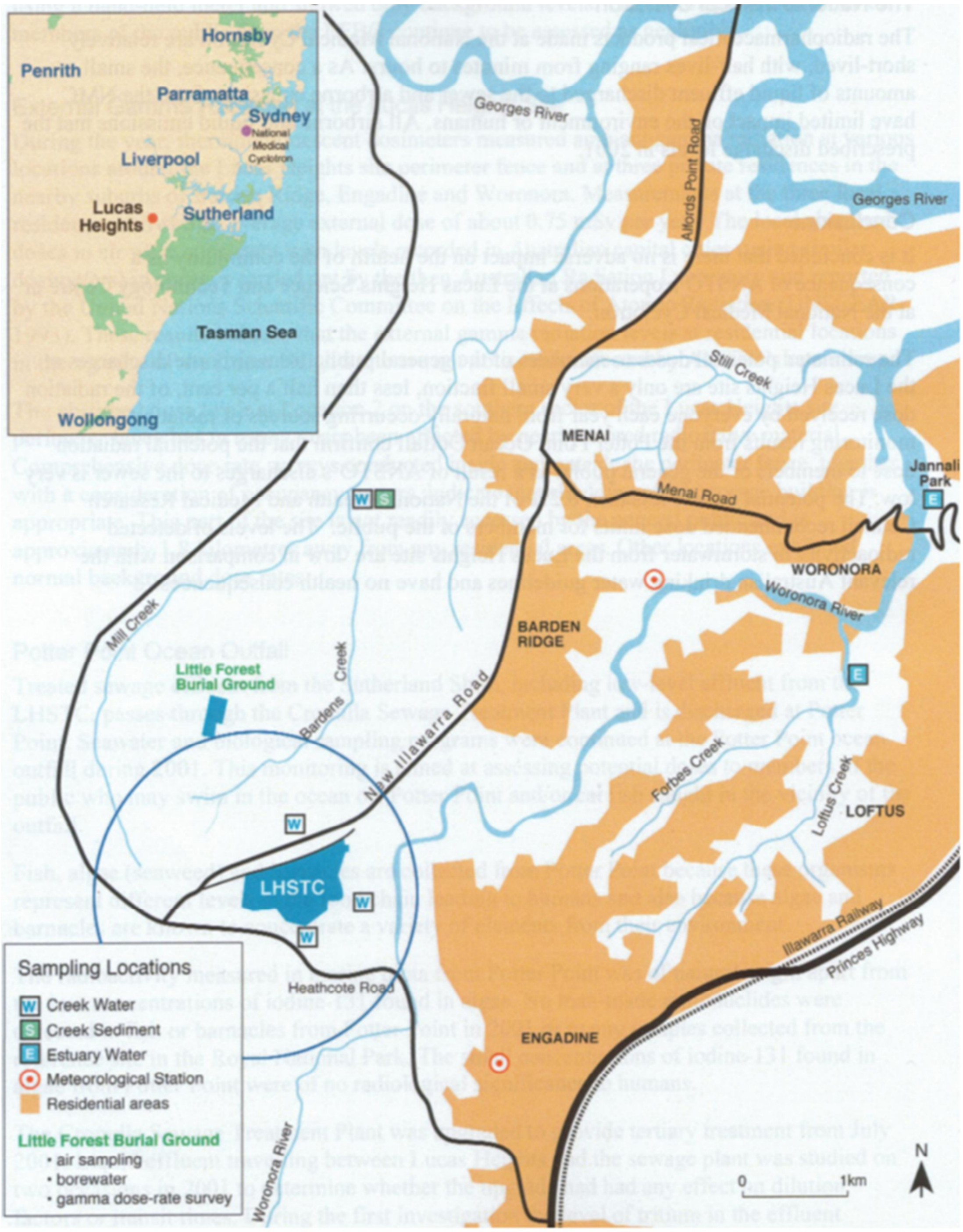


Figure 1. General location map for the Little Forest Burial Ground. Sampling locations for regular environmental monitoring are indicated.

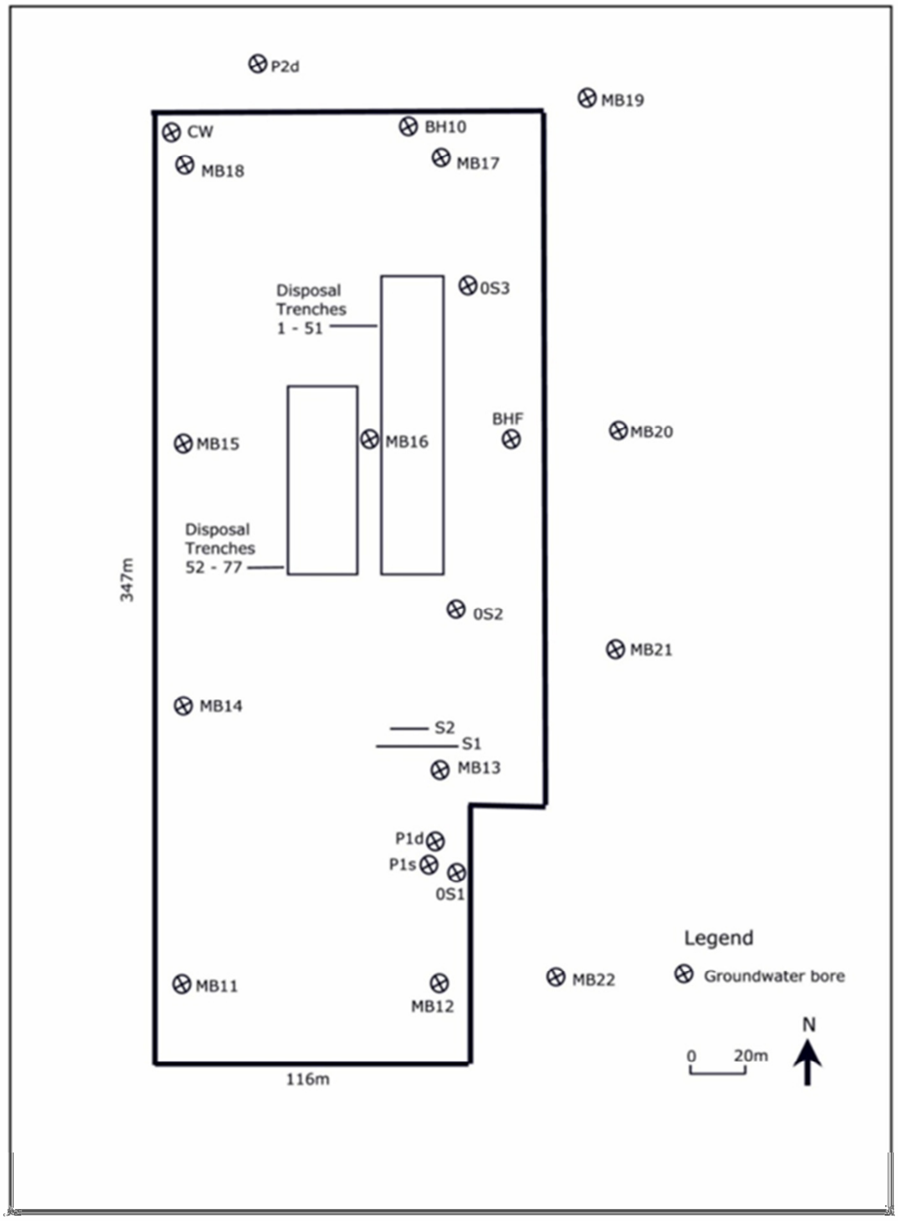


Figure 2. Plan view of the Little Forest Burial Ground indicating the groundwater bores sampled during regular ANSTO monitoring. There are two sets of trenches: an eastern set (trenches 1-51) and a western set (trenches 52-77). Two additional trenches (S1 and S2) were located to the south of the main trenched areas.

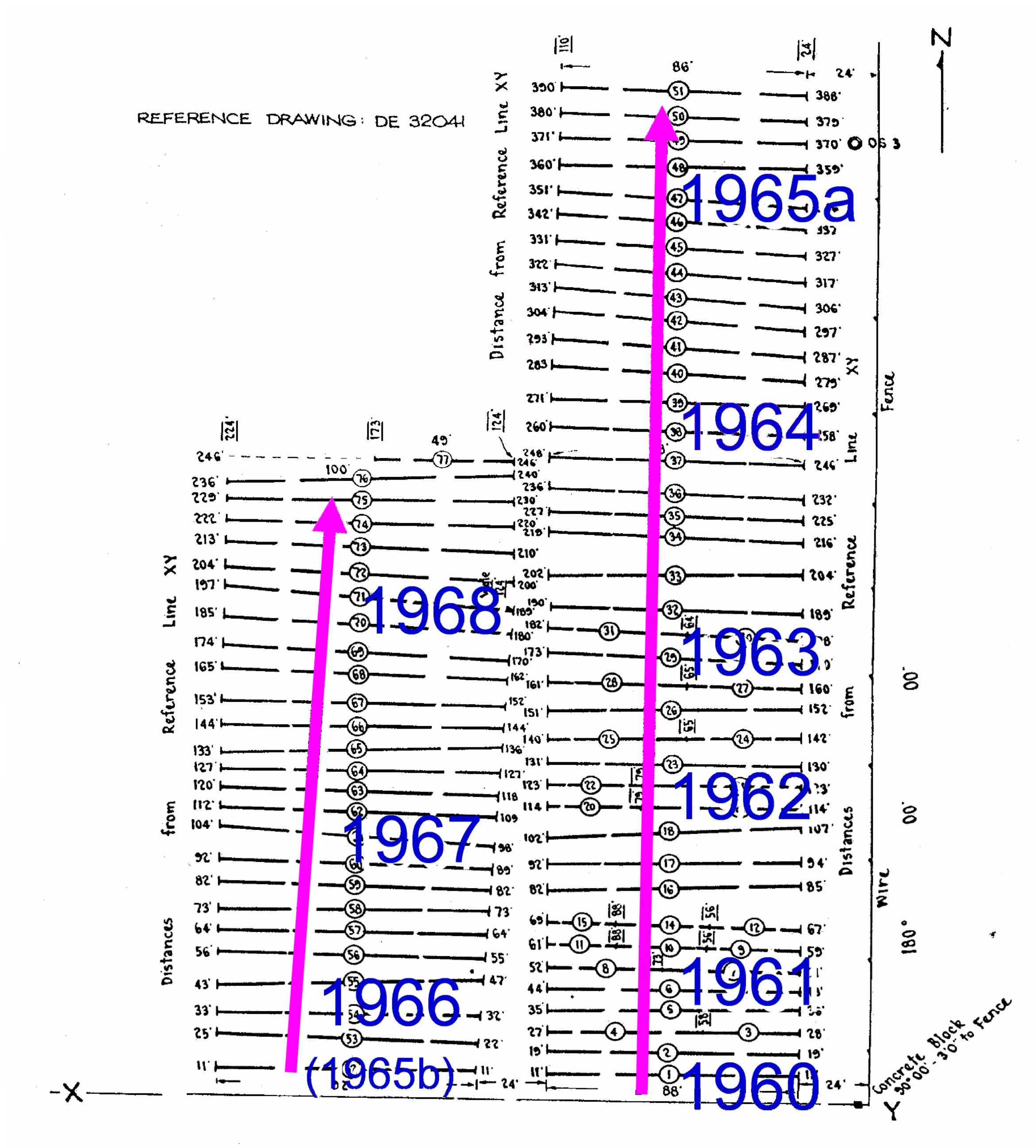
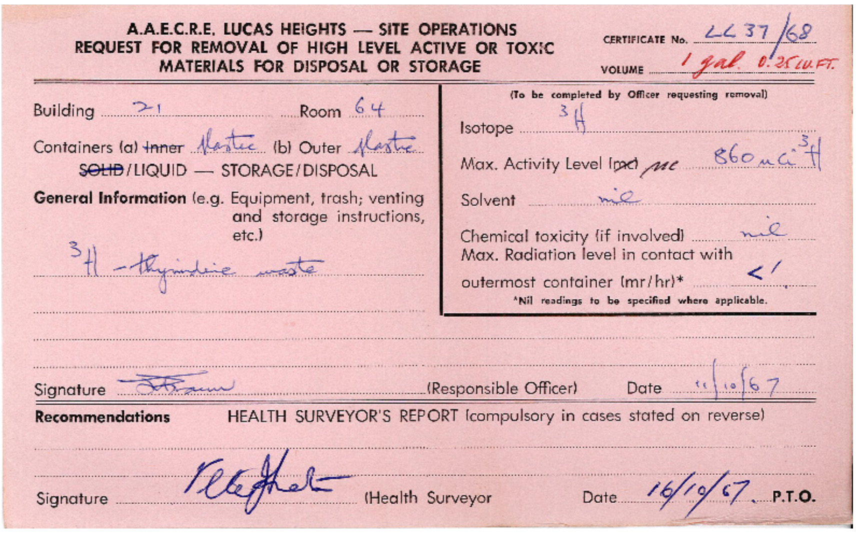


Figure 3. The sequence of filling of trenches at the LFBG from 1960 to 1968. Note that the 1965 disposals took place in the northern end of the eastern set of trenches (shown as 1965a) and the southern end of the western set (1965b). Two additional trenches (S1 and S2) were located to the south of the main trenched areas. These were filled in 1967 and 1968 respectively.

The burial ground is located in a lens of shale, and the trenches were excavated in the uppermost soil layers. The vadose zone extends from the surface to a depth of approximately 7–10 m, where the shale layer forms a localised perched water body due to the poor infiltration through the shale. Cores of soils extracted from below and adjacent to the trenches during the present research project have typically been unsaturated, with variable levels of soil moisture in perched horizons that appear to be discontinuous across the site. The parent shale is expected to act as a partial barrier to direct downward movement of groundwater into the aquifer in the Hawkesbury Sandstone below. Seeps related to the transition between the shale–sandstone interface emerge intermittently at the limits of the shale outcrop southeast of LFBG (AAEC, 1985). The Hawkesbury Sandstone has been interpreted as a layered aquifer system with groundwater occurring in discrete horizons with occasional vertical connections. The upper sandstone units are generally weathered and strongly jointed and fractured, resulting in a dual porosity aquifer in which flow may be dominated by the secondary porosity (McKibbin and Smith, 2000). The hydrological understanding of the site is being significantly augmented during the present ANSTO research project.

Waste characteristics and disposal operations

The waste is known to have contained various radionuclides including fission products (^{137}Cs and ^{90}Sr), tritium, activation products such as ^{60}Co (used in an irradiation facility at the site), ^{238}U, ^{235}U and ^{232}Th (with their decay products), and small (several gram) amounts of $^{239+240}$Pu and ^{233}U derived from the research into power reactor design. This latter activity also resulted in significant amounts of Be (~1100 kg) being present (AAEC, 1985). Types of information available include Waste Disposal Cards (pink cards), aggregated waste books, waste burial books, and photographs (see Figures 4 to 7).



A.A.E.C.R.E. LUCAS HEIGHTS — SITE OPERATIONS
REQUEST FOR REMOVAL OF HIGH LEVEL ACTIVE OR TOXIC
MATERIALS FOR DISPOSAL OR STORAGE

CERTIFICATE No. 2237/68
VOLUME 1 gal. 0.25 cu.ft.

Building 21 Room 64

Containers (a) ~~Inner~~ Plastic (b) Outer Plastic

~~SOLID~~/LIQUID — STORAGE/DISPOSAL

General Information (e.g. Equipment, trash; venting and storage instructions, etc.)

^{3}H - thymidine waste

(To be completed by Officer requesting removal)

Isotope ^{3}H

Max. Activity Level (~~mc~~) mc 860 μCi ^{3}H

Solvent nil

Chemical toxicity (if involved) nil

Max. Radiation level in contact with outermost container (mr/hr)* <1

*Nil readings to be specified where applicable.

Signature [signature] (Responsible Officer) Date 11/10/67

Recommendations HEALTH SURVEYOR'S REPORT (compulsory in cases stated on reverse)

Signature [signature] (Health Surveyor Date 16/10/67 P.T.O.

Figure 4. One of the approximately 4600 'pink cards' available for waste disposed at LFBG. These cards were filled out by the originator of the waste and checked by a health surveyor. Although these cards cover only a small proportion of the 47600 items thought to have been disposed (Isaacs and Mears, 1977), the information is a useful indication of the materials present at the site.

Figure 5. Excavation of trenches at LFBG.

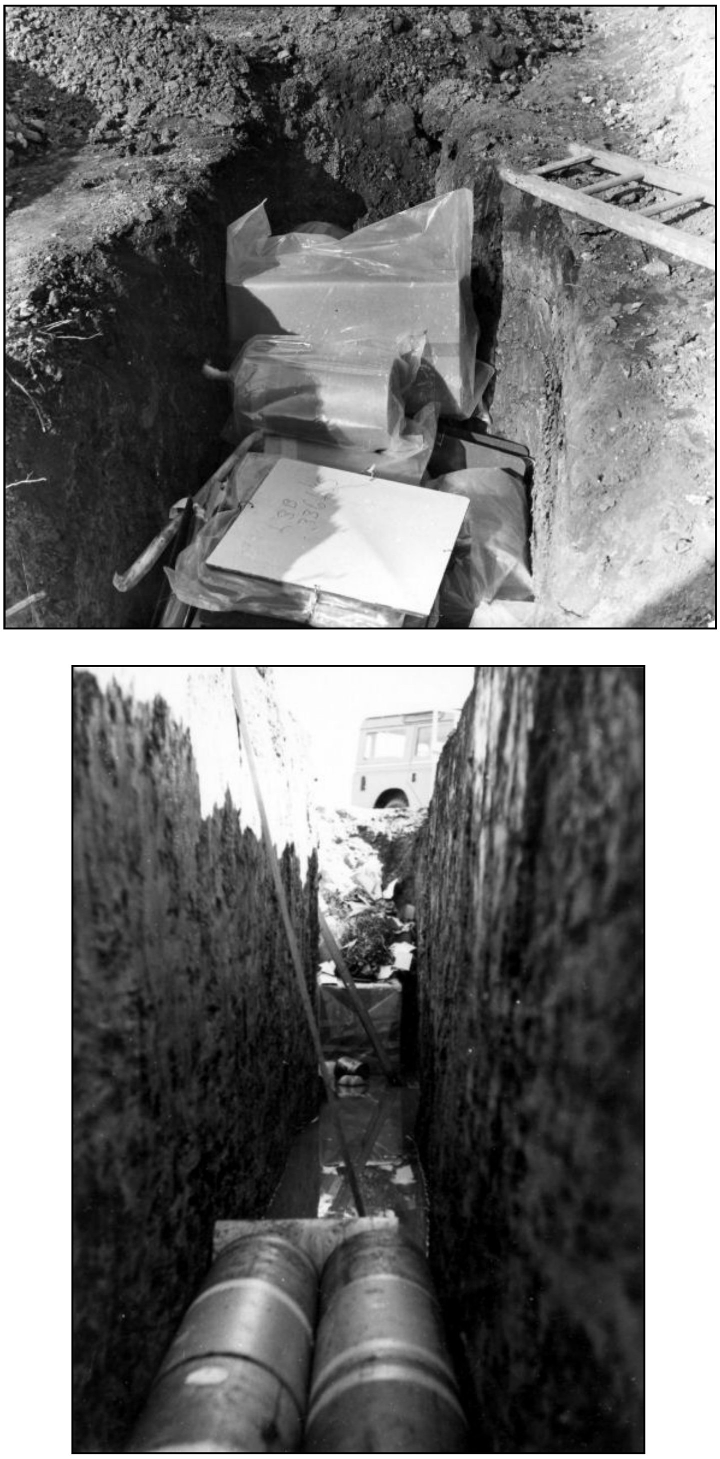


Figure 6. Waste materials emplaced in trenches at the LFBG during disposal operations. In the lower picture can be seen metal drums which may be some of the 760 waste sludge drums emplaced at LFBG.

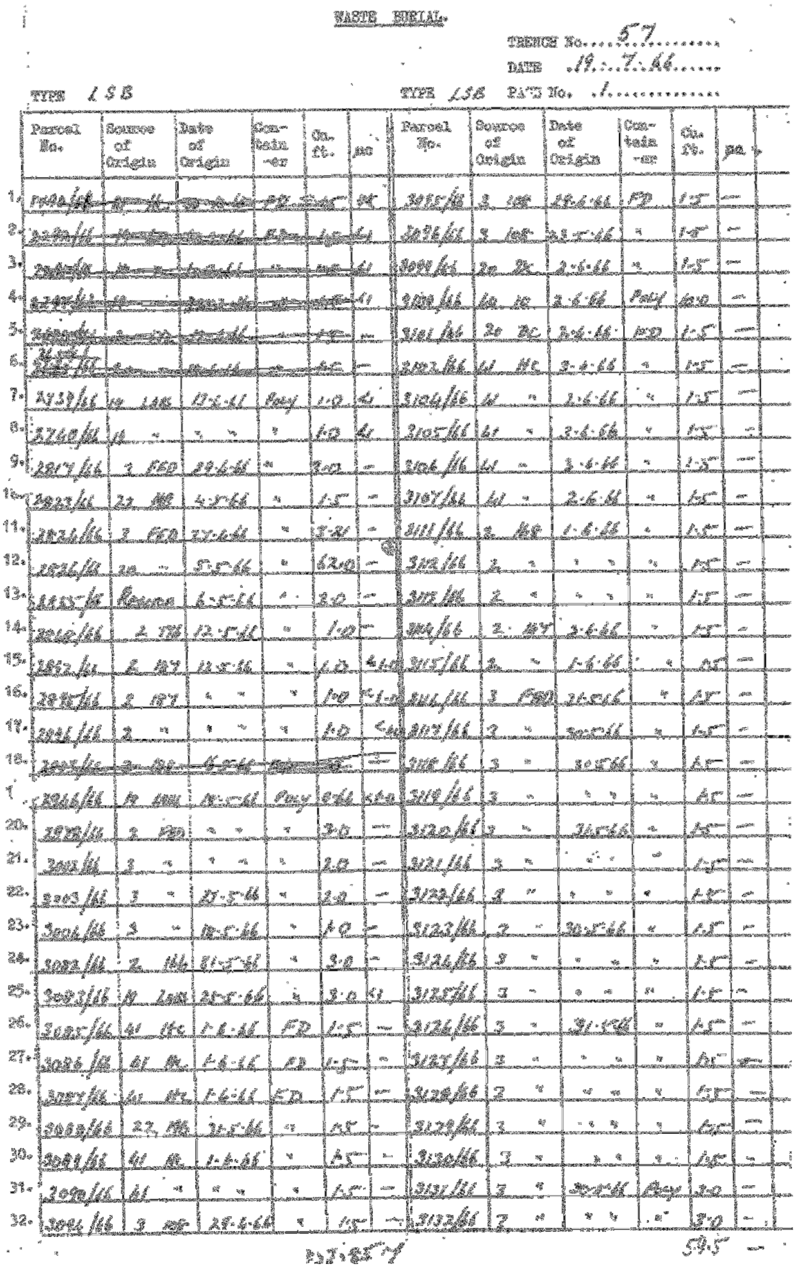


Figure 7. Part of a Waste Burial Record for LFBG (Trench 57). Although the information is less detailed than the waste cards (Figure 4) it forms the most complete set of information on items disposed at LFBG.

The wastes consisted of a large range of trash from laboratories handling radioactive materials, contaminated equipment, waste packages consigned from other organisations, and beryllium / beryllium oxide scrap (AAEC, 1985). The waste disposed included fissile isotopes in gram quantities (plutonium, ^{233}U and ^{235}U) as well as around 100 kg of the long-lived natural actinides (uranium and thorium) (Table 1). Numerous containers of liquid waste were disposed and a few items were incinerated on the site. Amongst the items disposed at LFBG were 760 drums of solidified sludge from the AAEC's effluent treatment plant.

The AAEC summarised information on the contents of the trenches (AAEC, 1985), which have been presented in Table 1, and Figures 8 and 9. The AAEC categorised radionuclides in groups I, II and III, which followed a descending order of radiotoxicity (based on IAEA, 1967). The radionuclides in each group are given in Table 2 (from Isaacs and Mears, 1977). The fissile and fertile contents of the waste were separately recorded, which is believed to have been because of criticality considerations and auditing requirements on nuclear material (AAEC, 1985). The records indicate a greatly increased rate of disposal of groups II and III radionuclides immediately before the cessation of disposal operations in 1968 (Figure 8).

Whilst the activities of the wastes were believed to be generally overestimated (AAEC, 1985), the activity of Group I (given in Table 1) appears not to include the plutonium (which, being a fissile isotope, was recorded separately in the 1985 AAEC summary). The contents of the sludge drums were also not accurately known, particularly in terms of alpha-emitters. In addition, whilst tritium is included in Table 2 (as a group VII radionuclide), the record of tritium disposed at the site is fragmentary. Indeed, its later detection in numerous groundwater samples from the site was regarded as "unanticipated" (AAEC, 1985). However, recent investigations of the "pink cards" (Figure 4) show numerous examples of disposal of tritium-contaminated items. It therefore appears that there are inaccuracies in the previous summary records, for example, in terms of the alpha emitters, contents of sludge drums and tritium disposed. A major aspect of the current research project undertaken by ANSTO is a full review of available disposal records.

	1960	1961	1962	1963	1964	1965a	1965b	1966	1967	1968	Total
Trenches filled	**1-5**	**6-18**	**19-26**	**27-36**	**37-46**	**47-51**	**52-53**	**54-61**	**62-70 and S1**	**71-76 and S2**	
Est. Activity (GBq)											
Group I	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.75
Group II	0.00	0.14	0.16	0.15	2.87	0.56	0.36	1.46	11.47	22.31	39.10
Group III	0.00	0.14	0.23	0.21	2.76	0.61	0.36	0.77	15.87	90.54	111.50
Fissile Content (g)											
Plutonium	0.00	0.00	0.00	0.00	0.00	0.00	1.98	4.44	0.46	0.00	6.9
Uranium-233	0.00	0.00	0.00	0.00	0.00	2.31	0.00	0.40	2.50	0.00	5.2
Uranium-235	0.00	5.30	23.60	0.00	18.20	8.90	0.00	17.60	15.00	3.41	92.0
Fertile Content (kg)											
Uranium	0.00	0.30	0.00	0.00	3.80	4.30	0.00	0.30	47.10	3.45	59.3
Thorium	0.00	2.30	0.00	0.00	0.00	18.60	0.00	5.60	13.40	8.17	48.1
Beryllium Content as Be/BeO (kg)	0.00	89.80	105.40	139.20	237.10	111.00	40.40	157.60	185.10	3.80	1070.0
Liquid Volume (m^3)	0.00	1.54	2.25	0.34	0.09	0.59	0.00	2.88	0.89	0.00	8.6

Note the following minor changes to the information given in AAEC (1985).

1. Activities converted from mCi (millicuries) to GBq
2. Error in Group II total disposed for 1965 was corrected
3. The 1965 amounts were split between 1965a and 1965b (see text).

Table 1. Summary of disposals at LFBG derived from AAEC records, as reported in AAEC (1985). Groups I, II and III are general categories of radionuclides, in descending order of toxicity (see text and Table 2). Note that the activity disposed during 1965 is split into two parts, which were disposed in different parts of the trenched area (see Figure 3).

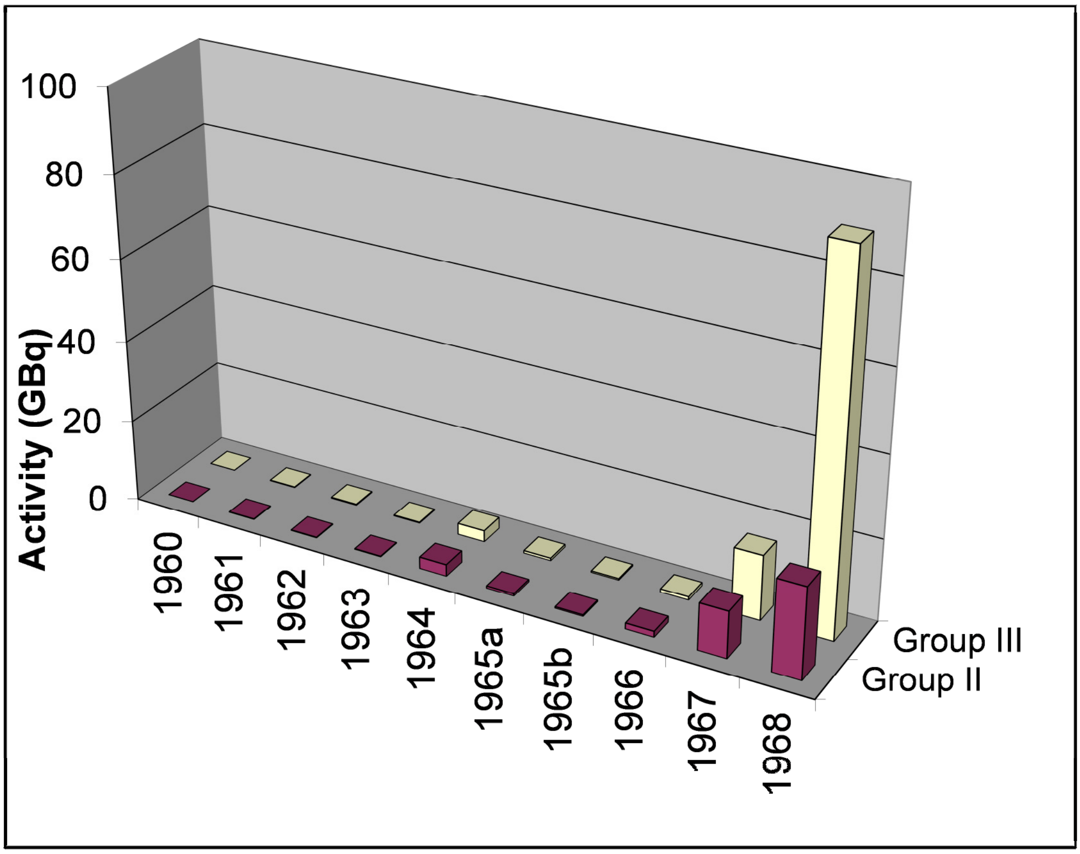


Figure 8. Total activity disposed of groups II and III radionuclides at LFBG for each year of operation (data from AAEC, 1985 and AAEC records). Note that the activity disposed during 1965 is split into two parts, which were disposed in different parts of the trenched area (see Figure 3). The activity of radionuclides in group I mostly comprised plutonium (see Figure 9).

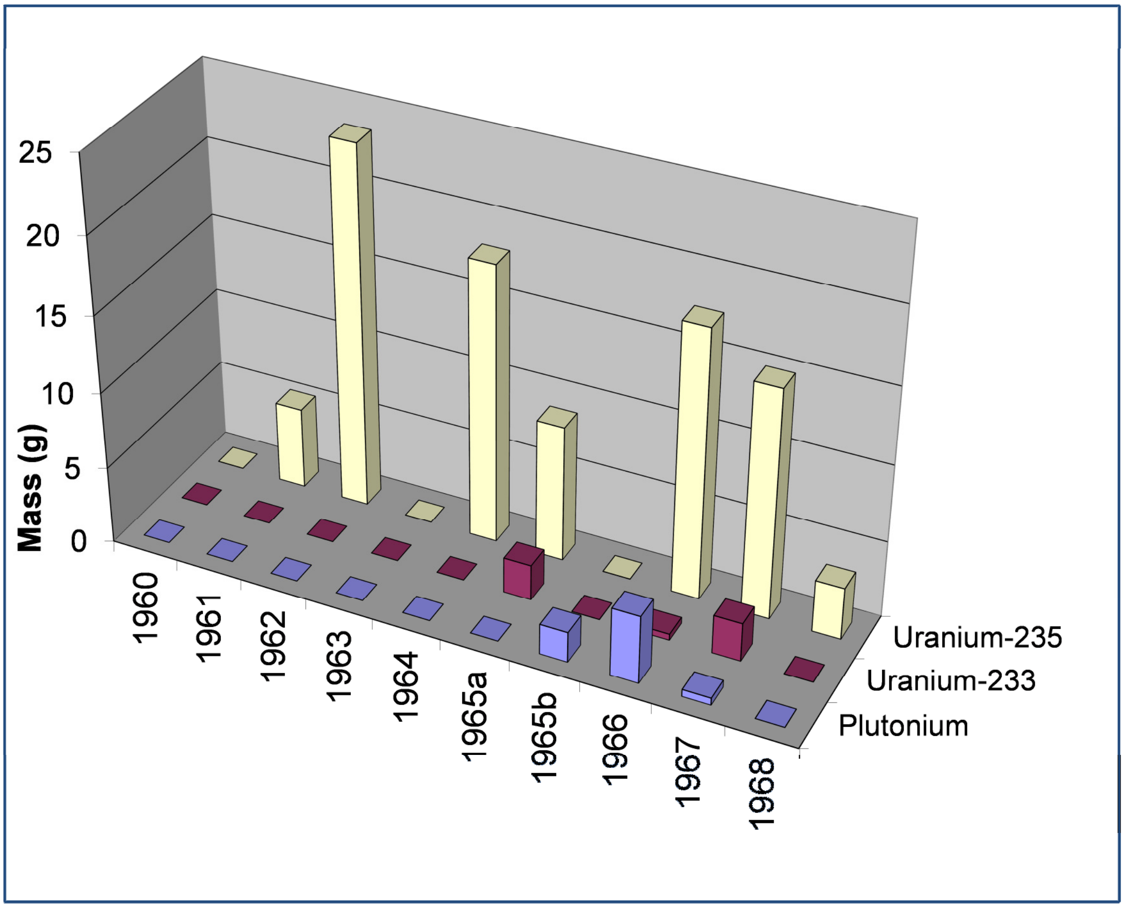


Figure 9. Total mass of fissile isotopes disposed at LFBG for each year of operation (data from AAEC, 1985). Note that the activity disposed during 1965 is split into two parts, which were disposed in different sections of the trenched area (see Figure 3).

SELECTION OF RADIOACTIVE NUCLIDES [IAEA 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}A, ^{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.

Group IV

^{198}Au, ^{7}Be, ^{82}Br, ^{14}C, ^{45}Ca, ^{38}Cl, ^{58}Co, ^{51}Cr, ^{135}Cs, ^{137}Cs, ^{64}Cu, ^{18}F, ^{55}Fe, ^{59}Fe, ^{42}K, ^{140}La, ^{99}Mo, ^{24}Na, ^{95}Nb, ^{63}Ni, ^{32}P, ^{103}Ru, ^{35}S, T-(in any form other than Group VII), ^{99}Tc, ^{132}Te, ^{65}Zn.

Group V

^{41}A (uncompressed), ^{135}Xe (uncompressed).

Group VI

^{85}Kr (uncompressed), ^{133}Xe (uncompressed).

Group VII

T (as T_2 or HT, or tritium activated luminous paint or tritium gas adsorbed on a solid carrier).

Table 2. Categorisation of radionuclides disposed at LFBG (From Isaacs and Mears, 1977).

Survey of AAEC / ANSTO Reports on LFBG

Regular environmental monitoring results of the LFBG, commencing from 1966, are documented in a series of environmental monitoring reports which are publically available and can be accessed through the ANSTO website. A recent example is Hoffmann et al. (2008). These results present data for the LFBG amongst a comprehensive set of other environmental monitoring measurements related to the AAEC / ANSTO operations at Lucas Heights (and elsewhere if relevant), including stack monitoring, liquid effluent, river water and sea water. The results for the LFBG typically relate to measurements of radionuclides in groundwater, particulate air-sampling and a gamma dose-rate survey. Occasionally, other environmental samples such as vegetation and soils have been reported. Standard methods such as gamma spectrometry, liquid scintillation counting, and total alpha and beta determinations have been employed for routine measurements.

The results of the environmental monitoring program in the past two decades have generally indicated that, with the exception of the tritium plume, detected levels of radioactivity at LFBG have not been elevated relative to background levels. For example, the continuous monitoring of gamma radiation in the middle of the trench areas, at a height one metre above ground-level, consistently indicates no significant difference from background levels. For tritium, the monitoring results from groundwater wells within the fence boundary have typically been below drinking water reference levels. However, there has been evidence of trench subsidence and surface contamination of radioactivity (AAEC, 1985). Following these incidents (discussed in more detail below), top dressing was done as “part of regular maintenance” and surface soil levels of radioactivity were “reduced to normal background levels” (Giles and Dudaitis, 1986). Since the early 1990’s, routine environmental sampling and analysis at LFBG has focused on groundwater, which has been considered to be the main radionuclide migration pathway from the site, together with the airborne samples. Total alpha- and beta- activities have been measured in groundwater, but not in surface soils over this period.

There have been several summary reports relating to various aspects of the LFBG, notably:

- Possible methods of disposal of the AAEC's low and medium level solid radioactive waste and an environmental impact assessment of the re-opening of an existing burial ground (AAEC/E421: Ellis, 1977).
- A study of the burial ground used for radioactive waste at the Little Forest area near Lucas Heights, New South Wales (AAEC/E427: Isaacs and Mears, 1977).
- The Little Forest Burial Ground – An information paper (Report DR19: AAEC, 1985).
- The series of ANSTO's environmental monitoring reports (mentioned above).

Both of the 1977 reports considered the re-opening of the burial ground for more disposal of radioactive waste. Isaacs and Mears (1977) concluded that the site was "not an ideal location for the burial of radioactive waste" due to problems caused by the hydrology of the site[1]. However, these reports left open the possibility of disposal of more waste at LFBG, with Ellis (1977) concluding that this would be a cheap option for waste disposal involving only "trivial" human exposure. Both of these 1977 reports mainly focused on gamma-emitting isotopes (particularly in the associated experimental work). Although the authors were aware of the disposal of plutonium and uranium-233, the implications of the presence of these long-lived alpha emitting isotopes were given little attention.

The "Information Paper" report (AAEC, 1985) contained considerably more information about the LFBG, including a summary inventory of waste disposed (see Table 1). The authors considered that the presence of significant quantities (over 1000 kg) of beryllium represented a sizeable potential hazard and rendered the site analogous to a "toxic material disposal site as used for, say, asbestos waste".

It was reported in the "Information Paper" (AAEC, 1985) that several aspects of the performance of the LFBG were not anticipated. The first was the detection of tritium in bore water from locations within and outside the fenced area. This was considered surprising because the AAEC had not "knowingly disposed of any significant quantity of tritium" (according to AAEC, 1985). However, recent examinations of the "pink

[1] These authors inaccurately described the hydrological problem as "the high water table that exists almost permanently", Recent investigations have shown that the problem is more likely a "bath-tubbing" effect raising the water level within the trenches, rather than a generally elevated water table (see below).

cards" (Figure 4) have shown numerous disposed items constituted a "tritium hazard" (although amounts of contained tritium were not specified) and included water contaminated with tritium, swabs from a deuterium plant room, contaminated lubricating oil, and sludge from deuterium pumps (a full report on the current survey of the LFBG disposal records is in preparation).

A second problematic aspect of the site was subsidence occurring within the trenches. This was possibly due to corrosion and collapse of major buried items such as glove boxes (AAEC, 1985). An example of subsidence which occurred shortly after the trenches were filled is shown in Figure 10. Subsidence has been an ongoing problem and has continued intermittently to the present day. According to the current conceptual model of the trenches, water infiltrates the disturbed area (i.e. the excavated and filled trenches) after periods of heavy rain. If the infiltration is sufficient, the water level in a trench can rise to the ground surface, saturating the trench, as observed in 2011 and previously reported (Ellis, 1977; AAEC, 1985).

The "Information Paper" (AAEC, 1985) reported that, "…by 1974, it was clear that some activity was being transferred from the buried waste to the overlying soil". This activity included ^{60}Co, ^{90}Sr, and elevated gross alpha activity, which was shown by subsequent analyses to arise predominantly from $^{239+240}Pu$ and ^{241}Am (assumed to be derived from decay of ^{241}Pu). It was stated that plutonium is readily adsorbed and "in almost all geochemical environments would be one of the last contaminants expected to be evident at the surface". Nevertheless, given the presence of plutonium at the surface, some mechanisms of plutonium mobilisation were proposed. In response to these findings, the trenched area was covered with another layer (approximately 30 cm) of soil, which was expected to provide an adequate barrier to radionuclide transport. Following this type of routine maintenance, it was asserted that "the burial site is as safe as any parkland" (AAEC, 1985).

About the time of the "Information paper" (AAEC, 1985) an air sampling program was initiated to detect possible airborne $^{239+240}Pu$ and beryllium, which might result from wind dispersion of contaminated surface soil particles. The environmental monitoring reports indicate that neither plutonium nor beryllium was detected, except for a possible trace of plutonium reported in a composite air large volume air sample (Giles et al., 1988). Negative results have been obtained for the subsequent years.

Figure 10. Subsidence occurred soon after the filling of trenches at LFBG and has continued intermittently to the present day. This picture was taken in March 1969.

ANSTO's current research activities at the LFBG

There have been significant changes in land use around the site with major industrial and municipal waste facilities operated in the vicinity since cessation of disposal operations at LFBG in 1968. Encroachment of Sydney suburbs into the areas surrounding Menai has occurred in recent decades, and plans exist for further developments that will place residences and recreational facilities closer to the LFBG site. Given the prospect of continued residential, recreational, and industrial activities in the vicinity, a better understanding of the LFBG site is needed.

A current ANSTO research project is taking a comprehensive approach to assessing the status of LFBG. The project includes detailed sampling and analysis of groundwaters, surface soils and vegetation. The work employs a range of measurements (including full alpha separation and identification of individual alpha-emitting radionuclides). The research applies advanced analytical techniques, such as accelerator mass spectrometry, which have not been employed in the routine environmental monitoring carried out at the LFBG in the past. The project is also assessing the available information and monitoring results for LFBG. The project has undertaken soil coring, geophysical surveys and installation of groundwater sampling wells during 2009-2010 (Figure 11).

A review of tritium data obtained since monitoring commenced (and supplemented by new measurements) has been completed (Hughes et al., 2011). An example of recent data compiled for tritium in water extracted from coreholes is shown in Figure 12.

Figure 11. Drilling undertaken at LFBG as part of current ANSTO research activities at the site.

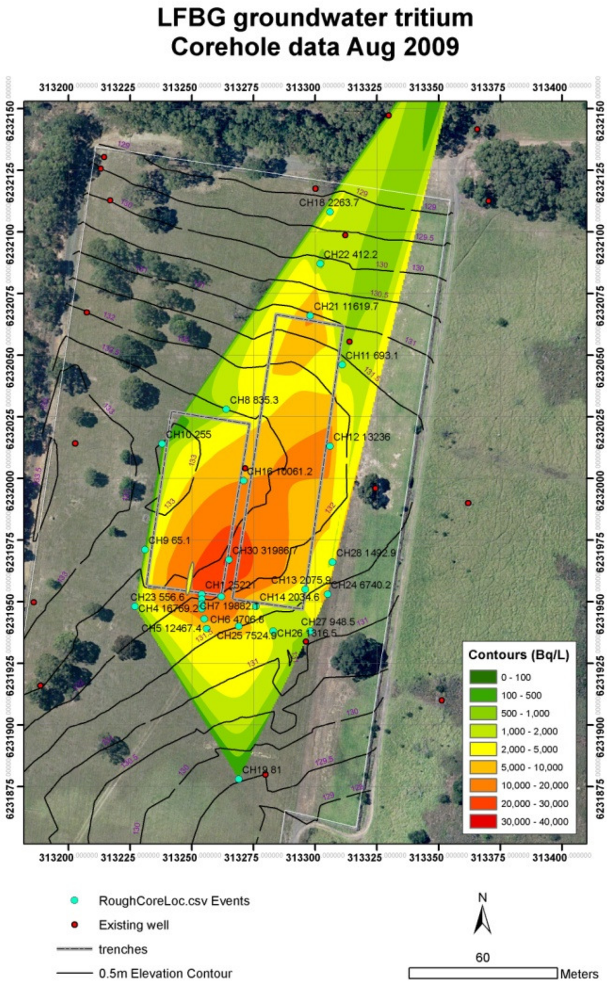


Figure 12. Data on tritium concentrations in water from coreholes sampled in August 2009 (further data and discussion can be found in Hughes, 2011).

Reports which are currently in preparation include:

- An overview of geology, geophysics and new sampling wells installed in 2009-2010
- a summary of the available information on disposal operations at the LFBG
- a review of routine environmental monitoring at the site since 1966.

Papers from ANSTO's research at LFBG which have been published in international journals include:

- J.R. Twining, C.E. Hughes, J.J. Harrison, S. Hankin, J. Crawford, M. Johansen and L. Dyer (2011). Biotic, temporal and spatial variability of tritium concentrations in transpirate samples collected in the vicinity of a near-surface low-level nuclear waste disposal site and nearby research reactor. Journal of Environmental Radioactivity, 102: 551-558.

- J.J. Harrison, A. Zawadzki, R. Chisari and H. Wong (2011). Rapid determination of uranium, thorium, plutonium, americium and strontium activities in water, soil and vegetation. Journal of Environmental Radioactivity, 102: 896-900.
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These papers have focused on the hydrology of the site as indicated by tritium data (Hughes et al., 2011), analytical methods for radiochemical analysis (Harrison et al., 2011), the uptake of tritium in vegetation (Twining et al., 2011) and assessing various methods of modelling the resulting dose to biota (Johansen et al., 2012).

The results of the ongoing work will be summarised in various ANSTO reports (including the regular environmental monitoring reports) and papers from the project are being published in the refereed scientific literature. One of the objectives of the research project is to provide information for evaluating future management options for the site. These options include continuation of the current security and monitoring regime, and possible additional management and remediation strategies.

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