Waste Disposals at the Little Forest Site – Procedures, Records and Significant Events

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LITTLE FOREST LEGACY SITE – TECHNICAL REPORT

WASTE DISPOSALS AT THE LITTLE FOREST SITE – PROCEDURES, RECORDS AND SIGNIFICANT EVENTS

T.E. Payne, J. Shatwell and
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Purpose

The Little Forest Legacy Site (LFLS) is a legacy trench site operated during the 1960s, which was used to dispose of low-level radioactive waste and other types of waste. The main objectives of this report are to:

- Provide an overview of the waste disposal procedures followed at the Little Forest site, including the role of the burial ground store.
- Describe the various types of relevant documents and how they are related.
- Evaluate the extent to which the documents can be considered to be complete or accurate.
- Highlight possible omissions and inconsistencies between documents.
- Discuss individual waste types disposed at Little Forest.
- Present a summary of significant events which relate to waste disposals and the inventory.
- Review the potential relevance and availability of key pieces of additional information which may be missing, may have been previously overlooked, or may have been given inadequate attention.

The comprehensive information in this report has been concisely summarised in the following paper by the same authors: *Priority issues and key findings from evaluation of disposal records for a legacy radioactive waste site.* **Journal of Radiological Protection, Volume 41 (2), page S24, (2021).** This paper provides an overview of the research and its major findings.

Scope

The current document focuses on the disposal process, the available records of the contents of the trenches, and events relevant to the operations. It reviews the information presented in previous summary documents.

Although this report reviews the data sources used in previous estimates of the inventory, and identifies some errors and inconsistencies in these previous sources, it does not attempt to provide a corrected inventory. This topic will be addressed in a related report (ANSTO E-789).

Note on units

In this report, the units which were in use at the time (e.g. milliCuries / mCi) are used when describing operations and applicable limits on disposals.

Abbreviations

AAEC Australian Atomic Energy Commission (predecessor of ANSTO).

ANSTO Australian Nuclear Science and Technology Organisation.

BGS Burial Ground Store (a building used to store waste on the LFBG site).

EHM Estimates of Hazardous Materials (a document containing a waste inventory for the site, compiled shortly after disposals ceased). Information from the EHM is summarised in Appendices D and E of this report.

HIFAR High Flux Australian Reactor.

LFBG Little Forest Burial Ground (the name of the site when disposal operations were underway and subsequently until 2014). This term is used in this report when referring to disposal practices during the 1960s.

LFLS Little Forest Legacy Site (the name of the site since 2014). This term is used in this report when referring to the current site status.

MFP Mixed Fission Products.

RN Radionuclide.

SAC Safety Assessment Committee (an AAEC committee during the operational period).

SDR Scrap Disposal Report.

WBB Waste Burial Book(s). A set of books in which disposals in each trench were recorded, covering the majority (but not all) trenches.

WBR Waste Burial Record. A single page summary document for each trench prepared during 1968 (the final year of disposals). The WBRs for trenches filled during 1968 were prepared a few weeks after the trenches were filled. The WBRs for other trenches were compiled retrospectively.

Abbreviations for waste types

Note that the terms “low”, “medium” and “high” do not correspond to current definitions of activity levels.

- LL – low level liquid
- LLB – low level liquid contaminated with beryllium
- LS – low level solid
- LSB - low level solid contaminated with beryllium
- MS – medium level solid
- HS – high level solid
- HL – high level liquid
- FMS – fissile medium level solid

Acknowledgements

We thank ANSTO Waste Operations for access to records and useful discussions. The assistance of ANSTO Records staff and National Archives in obtaining some of the material discussed in the present report is greatly appreciated. The authors are indebted to Patrick Mahony who prepared the original description of the LFBG Records. Eve Chong also undertook considerable work to improve the organisation and documentation of available records.

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1. Summary of this report

The Australian Atomic Energy Commission (AAEC) disposed of low-level radioactive waste at a site in the Little Forest area on the southern periphery of Sydney between 1960 and 1968. The waste was disposed in excavated trenches according to the prevailing practices and standards at the time. During the operational period, the site was known as the Little Forest Burial Ground (LFBG)[1]. In recent years, the Australian Nuclear Science and Technology Organisation (ANSTO) has been implementing a detailed scientific study of the status of the disposal site, now referred to as the Little Forest Legacy Site (LFLS). This study has included sampling of vegetation, groundwater and soils. As part of the research, documents related to the disposal operations have been reviewed. The findings of this study are reported in the following chapters.

Chapter 2 of the report provides an overview of the waste disposal process followed at Little Forest (including the role of the burial ground store).

Chapters 3 and 4 summarise the various types of source documents which contain information on disposals. Although numerous records have been preserved, there are nevertheless some information gaps.

Chapter 5 describes the contemporary summary documents pertaining to waste disposals at the Little Forest site, focusing on any information regarding the inventory of waste disposed at LFBG.

Chapter 6 discusses the disposal of sludge drums at Little Forest. The radionuclide content of these drums was not fully taken into account throughout disposal operations, and there were significant changes in documenting the sludges during the final year of operations at LFBG.

Chapter 7 reviews various events which occurred during the disposal years, which impacted the waste disposal practices, and the items disposed at the site. It also discusses the factors which may have led to the cessation of disposal operations in 1968.

Chapter 8 reviews trench disposal practices during the operational period based on a detailed analysis of the available records, including pink cards, waste burial books and various disposal summaries.

Chapter 9 summarises some non-radiological (chemical and physical) aspects of the waste disposals.

Finally, **Chapter 10** reviews some of the issues which were subsequently raised about the LFLS site. These issues influenced the monitoring and management of the site over the decades subsequent to the disposals. Some of these topics remain relevant to the future management of the site.

The **Appendices** are an important component of this report. These are intended to provide a directory of the available information on the disposals at the site, which will continue to be preserved. The Appendices are as follows:

- Appendix A: Related reports from current research at the LFLS
- Appendix B: Counts of Pink cards
- Appendix C: Number of records in Waste Burial Books and Burial Ground Store book
- Appendix D: Summary of wastes disposed in trenches
- Appendix E: Waste volume, beryllium and radionuclide inventory of trenches
- Appendix F: Summary of Scrap Disposal Reports

The present investigation has greatly clarified how the existing summaries of LFLS disposals were compiled and has reviewed the sources of the published inventory estimates. This helps in evaluating the uncertainties associated with these estimates, thereby improving the confidence in the outcomes of human health and environmental dose modelling ((Johansen et al., 2012; Johansen et al., 2020). The work described in this report has resulted in a greatly improved understanding of the disposal operations at the LFLS, which will facilitate informed decisions about the management of the site.

[1] In this report the terminology LFBG (rather than LFLS) will generally be used when referring to practices which occurred during the 1960s (at which time the site was an operational site rather than legacy site).

2. Overview of disposals at LFBG

2.1. The typical waste-disposal process

The objective of this section is to give a general overview of the procedures leading to waste disposals at the LFBG site during the 1960s. The first step in the process of waste disposals employed by the AAEC was for the officer who initiated the disposal request to arrange for the removal of unwanted items from their work area. The work area generating the waste could be a laboratory, a facility such as the HIFAR reactor, or another part of the AAEC, including the Waste Operations section. The waste was accompanied by a 'pink card' containing information such as the building of origin of the waste, the type of container and general information on the contents of the waste package.

The item was examined and assessed by a health surveyor, who reported on the type of hazard, monitored the amount of external radiation, entered this information and any relevant advice on the pink waste card (e.g. "do not open"), and removed the items for storage (and ultimate disposal).

It appears that the Waste Operations section kept books containing a record of the waste packages of different types as they were received. The details of each package were recorded sequentially in these books. For example, a set of books covering the LSB (low-level solid beryllium contaminated) waste items generated in most of the financial years during the disposal period has been retained. However, the corresponding books for other types of wastes do not exist, which presumably means that the information was never collected or has since been lost.

The items were temporarily stored before disposal, either on the main Lucas Heights site or at the Little Forest site. Many items were stored under cover in the Burial Ground Store (BGS) at the LFBG, and sludge drums were stored nearby in the open. The BGS was used to store items until they were ready for disposal (Figure 1). Some items spent a significant period of time in the store, which was apparently due to their elevated external dose rates. As this radiation was mostly due to the presence of short-lived radionuclides, the storage of the items (in some cases for years) usually resulted in a sufficient decrease of the dose rate for the items to be deemed suitable for burial.

At the time of disposal, all items buried in each trench were reported in Waste Burial Books (WBBs). The waste burial books are the most complete documentation on disposals at Little Forest, up until trench 67, after which it appears they were no longer compiled (although it is possible that the later WBBs have been lost). Following the cessation of information being recorded in the burial books, another document, the "burial ground store log book", provides fragmentary information which assists in assigning items to specific trenches (although this record is clearly incomplete).

Figure 1. The burial ground store during the operational period.

None of the available waste burial books include trenches 71 to 76 (and S2) filled in 1968. There are sets of pink cards (see Section 3.1), which appear to be incomplete, for these trenches. Thus, the assignment of the items on these cards to individual trenches is somewhat uncertain. While every set of documents regarding the LFBG operations is fragmentary, the comparison of the various sets of records and the available summary documents provides some useful information relevant to the disposals at the site.

At the time of the development of the LFBG as a disposal site, trench burials were an internationally accepted method for disposal of low-level radioactive wastes; and trench facilities were operational in numerous countries (including the UK and the USA). Many of these sites were used to dispose much larger quantities of radioactive wastes than are present at the LFLS (Payne et al., 2013). In the early days of trench disposal systems, it appeared that there was limited migration of radionuclides from the disposal trenches at these sites. However, senior AAEC staff became aware of significant issues which had become apparent at some of the overseas sites (Payne, 2015), and the limitations of this method of disposal became an increasing concern during the LFBG operations. This was probably a factor in the cessation of disposals in 1968.

2.2. Types of wastes

Approximately 50,000 items were buried at the LFBG. Of these, just over 36,000 items were recorded in the burial books (WBBs), which cover trenches 6 to 66. The other items were apparently buried in:

- Trenches 1-5, for which no itemised records exist.
- Trenches 67-70. Some information on this period can be deduced from the incomplete BGS inventory (compiled on 17 August 1967). However, this is not a complete list of buried items, but a list of items stored within the BGS on this specific date. There are also some pink cards for these trenches.
- Trenches 71 to 76 (for which there is an incomplete set of ~1600 pink cards).

The types of waste disposed at LFBG were classified into the following categories, which were indicated on the Pink Cards and in the WBBs:

- LL – low level liquid
- LLB – low level liquid contaminated with beryllium
- LS – low level solid
- LSB - low level solid contaminated with beryllium
- MS – medium level solid
- HS – high level solid (note that this did not correspond to the category of highly active, heat producing waste used in modern terminology)
- HL – high level liquid
- FMS – fissile medium level solid

Appendix B provides a summary of the distribution of the existing cards between these categories. The distribution of the items as recorded in the WBB records is presented in Appendix C.

Of the ~36,000 items in the WBBs, over 21,000 items were LSB and 15,000 items were LS. Thus, these two types of waste streams were by far the most abundant, although a different categorisation was used towards the end of the disposal period (when the final trenches were filled, and the WBBs were no longer in use). Approximately 300 liquid items (LL and LLB) were either buried or burned, with much smaller numbers of items in other categories being disposed. However, disposal of items in the HS, MS, and FMS categories only occurred after the WBB records had ceased to be compiled. Thus, the items in these categories were disposed in the final few trenches, for which we must rely on the fragmentary pink card information.

2.3. Trench layout and disposal methods

The LFBG trenches were filled sequentially from 1960 until the cessation of disposal operations in 1968. The layout of the trenches is shown in Figure 2. From 1960 to 1965 the eastern set of trenches were progressively filled, moving in a northwards direction. Disposals in 1965 took place both in the northern end of the eastern set of trenches (shown as 1965a) and the southern end of the western set (1965b). Adjacent trenches were subsequently filled during 1966 to 1968. The final trench excavated was Trench 77 in 1968 (see Section 8.10.7).

Some of the earlier trenches were of a shorter length, constructed end-to-end so that the combined trench length was similar to a full-length trench (e.g. trenches 3+4; 9+10+11; 12+14+15; 27+28; 30+31, and others, as shown in Figure 2). Trench 13 is not indicated on the diagram and its location is uncertain. Liquids were apparently burned in this trench (over 300 gallons). The significance of the breaks in the trenches indicated in the drawing is not known. The fence indicated near the eastern end of the trenches (Figure 2) has since been moved further away from the nearest trenches.

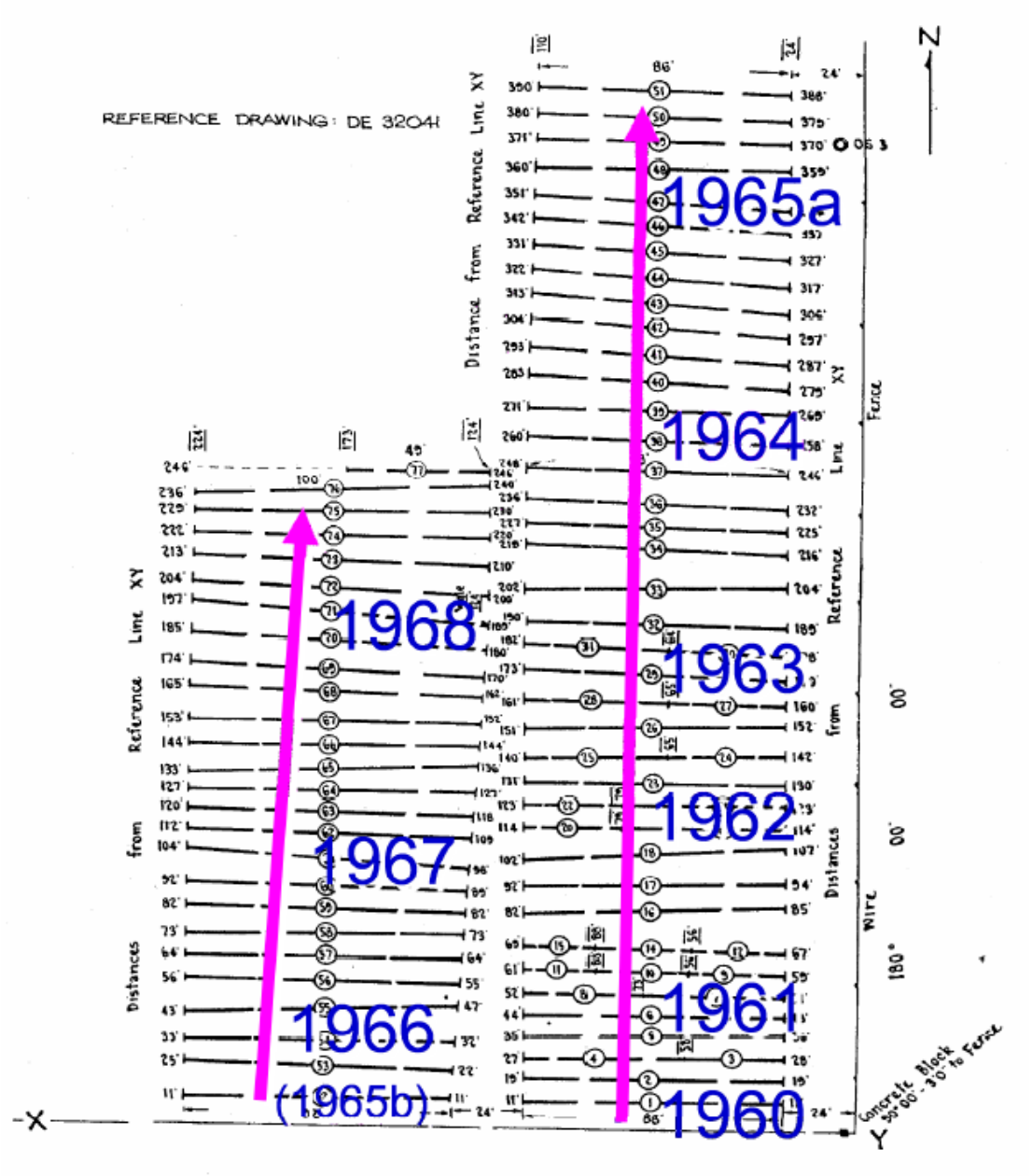


Figure 2. Layout of the main trenched area and order of trench-filling.

The main trenched area contains trenches numbered from 1 to 77, and there were two additional trenches (S1 and S2) some distance to the south of the main trenches (see Figure 2 in report E-780). These trenches were filled in 1967 and 1968 respectively (Payne, 2012). Based on the disposal records, it is thought that trenches S1 and S2 were filled when other trenches were simultaneously being filled in the main trenched areas. The circumstances surrounding the filling and the contents of individual trenches are considered in greater detail in Chapter 8 (S1 and S2 are discussed in Sections 8.9.6 and 8.10.3). The dates of filling of trenches are given in Appendix D (from the EHM document[2]).

At the time when disposal operations started, a tractor with a back-hoe attachment was purchased by the AAEC to excavate the trenches, as shown in Figure 3. The tractor was also used as a bulldozer for backfilling. A general description of the method normally adopted to fill the trenches suggests that a trench disposal operation would take around five days – including two days to excavate, a day to transfer the waste and two days to back-fill (Ellis, 1977). It is unlikely that the machinery used in these operations would have penetrated deep into the shale layer below the trenches (if it was encountered). Furthermore, the amount of spoil generated (Figure 3), suggests that large amounts of unconsolidated materials may have been present in the vicinity of the disposal trenches.

Figure 3. Trench excavation and backfilling operations.

The dimensions of the trenches have been reported (Isaacs and Mears, 1977) as “nominally 25 m long, 0.6 m wide and 3 m deep and spaced 2.7 m apart”. As noted above, some trenches were much shorter than 25 m (see Figure 2). For example, Trenches 3 and 4 have a combined length of approximately 25 m, as do trenches 9-11 and 12-15. Given that the trench dimensions were regarded as ‘nominal’, there may have also been some variation in width.

According to a contemporary source (EHM[2]), some liquid waste was disposed in Trench 13, but this trench is absent from the trench diagram. (The findings of the present project indicate that these items were burned, see Section 2.4). Based on the same source, Trench 77 was partially dug when the direction to cease disposals was received and was subsequently filled with inactive waste during the clean-up of the site. Thus, the total number of known waste-filled trenches at the site comprises Trenches 1-76 (excluding 13), as well as S1 and S2.

[2] “Estimates of Hazardous Waste Buried at the Little Forest Burial Ground”, a document apparently prepared around 1970. This document is referred to as the “EHM” document and it was used to compile the information presented in Appendices D and E of the present report.

A variety of bags and containers were used to contain many of the waste items, including plastic and 'sisalkraft' bags, fibreboard drums, metal drums, metal paint tins, glass or plastic carboys, and cardboard boxes. Some of these packages can be observed in contemporary photographs of partly filled trenches (Figure 4). Near the entrance to the site was the storage hut (BGS), used for interim decay of short-lived isotopes in some higher activity wastes (Figure 1 and Figure 5). The LFBG site was used for the disposal of a large number (~800) of 44-gallon drums filled with effluent sludge. Some of these drums can be seen in Figure 5 (in a line to the top right of the photo, near the BGS). Initially the drums were in interim storage at the LFBG (pending a decision being made on their disposal). A contemporary account indicates that some of the drums became corroded and fragile, to the extent that they were not transportable (Bonhote, 1964). Subsequently, numerous drums were disposed in the trenches at the site, commencing with Trench 39 during May 1964 (see Appendix D).

Figure 4. Waste emplacement in the Little Forest trenches. The drums in the photograph on the right appear to be small chemical drums (rather than 200 L sludge drums).

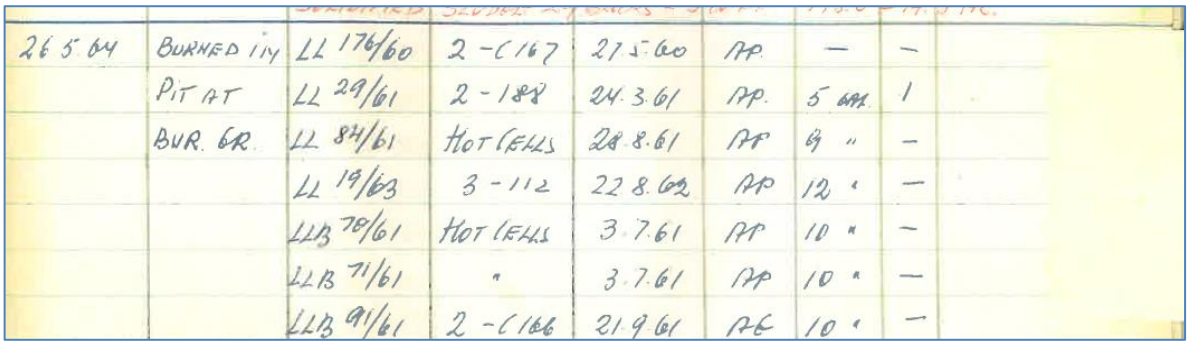
Figure 5. General view of the LFBG site (circa 1964). Numerous drums appear to be located near the storage hut to the right of the photograph.

2.4. Waste burnings

The burning of items at LFBG has not been previously reported. However, during the examination of the documents, numerous records of items being burned were uncovered (e.g. Figure 6). Incidences of burned items include:

- Liquid waste burned in “Trench 13” on 4 July 1961. The summary document (EHM) gives a volume of 313 ½ gallons (1187 litres). This considerably exceeds the volume of the wastes reported on the 5 available pink cards for this trench (totalling 160 Litres). Solvents included acids and toluene. One card provided details of radionuclide content of an item (described as MFPs/Cs-137). Trench 13 is not indicated on the trench diagram (Figure 2) so the exact location of this event is unknown.
- Between 26 and 28 May 1964, fifteen items totalling over 100 gallons were burned in a pit at an unknown location (Figure 6). These wastes were in categories of LL and LLB and originated from the years 1961 and 1962 (based on the item numbers and dates of production). Therefore, they had been stored for some time. These items included 55 litres of uranyl nitrate in organic solvent containing 5.3 g of U-235.
- A total of over 160 gallons of liquids were burned on 31 August 1964 and 4 September 1964. The pink cards for some of these items have been located. The items consisted of waste oil (from both machinery and vacuum pumps), and some significant quantities of waste solvents (some from decontamination of manipulators). One item contained 10 gallons of mixed solvents (toluene, ethanol, benzene). Radionuclides present included MFP, Th, U_{nat}, and C-14. A number of items reportedly contained “Turco” solvent (the specific solvent composition is unknown). The presence of beryllium was noted for some items. As with most previous burnings, these items were not reported in the available summary documents, such as the EHM and the waste burial records (WBRs), which were organised by trenches and omitted burnt items (see below).
- There is a record[3] of waste being burned for an external organisation. According to this record, “waste was delivered to site on 5/4/1968”, and part of the waste (liquid xylene) was burned, and all other waste in the consignment was buried (possibly in Trench 72).

Additionally, a set of 5 pink cards from liquid wastes disposed on 4 Oct 1962 was located. This date is between the disposals in Trench 23 and Trench 24. It is possible that these items may have been poured into a trench or burned. Although records of later burnings after 1964 are absent (other than the incident of 5 April 1968), this does not necessarily mean that burnings had ceased.



26 5 64	BURNED IN	LL 176/60	2 - C167	27.5.60	AP	—	—
	PIT AT	LL 29/61	2 - 188	24.3.61	AP	5 GAL	1
	BUR. GR.	LL 84/61	HOT CELLS	28.8.61	AP	9 "	—
		LL 19/63	3 - 112	22.8.62	AP	12 "	—
		LLB 70/61	HOT CELLS	3.7.61	AP	10 "	—
		LLB 71/61	"	3.7.61	AP	10 "	—
		LLB 91/61	2 - C166	21.9.61	AE	10 "	—

Figure 6. Record of items burned in a pit at the burial ground on 26 May 1964. The columns included date of disposal, location (usually trench number), item numbers (preceded by LL and LLB in this case), rooms / dates of production, type of container (in this case the exact meanings of the entries in this column are unclear), volumes (gallons) and activity (mostly blank in this instance).

[3] File note dated 5 April 1968 by LH Keher (hand-written).

2.5. The total radioactivity disposed

A feature of the disposals at the LFBG site is the marked acceleration of the total amount of activity disposed in the final 2 years of operation (i.e. 1967 and 1968). This increase can be seen in Figure 7, which was compiled from data in the EHM document (see Appendices D and E). The categorisations of radionuclides in Figure 7 are based on general categories of radionuclides in use at the time of disposals (Payne, 2012), whereby Groups I, II and III comprised a descending order of toxicity. Group I was a more hazardous and toxic set of radionuclides and included long-lived actinides such as Pu-239, Pu-240, and Am-241. Group II contained radionuclides that were considered to be less toxic, such as various mixed fission products and U-233 (see Section 5.4.1).

There were no disposals of Group I radionuclides noted in the EHM summary document before Trench 71 (filled in February 1968)[4]. However, the available SDR documents clearly show that Pu-239 and Pu-240 were disposed in some of the earlier trenches. These Pu disposals were reported in the EHM (see Sections 3.4 and 5.1), but were excluded from the total Group I activity in the EHM. Another significant aspect of the existing inventories was the omission of the Group I activity contributed by many of the disposed sludge drums (see Section 6). The Group I activity of approximately 75% of the sludge drums was omitted from the previous inventories. The summary of disposals of fissile isotopes (according to the EHM) is shown in Figure 8.

There were several reasons for the accelerated rate of disposals in later disposal years. A major factor was the relaxation of the surface dose rate criteria applied to disposed items. Until the decisions reported in document SAP/P5, which was approved on 26 July 1967 (Section 7.2), all buried waste was classified as “low-level” and had a dose rate less than 5 mR/hr. After SAP/P5 was introduced, the allowable dose rate was raised to at least 200 mR / hr (there is evidence that an intermediate criterion of 25 mR/hr was proposed in 1964, but this was apparently rejected). The activity disposed was estimated from the surface dose rate, hence the greater doses on the later items translated into higher estimates for disposed activity. Another relevant factor was the emptying of the burial ground store during this period. The store had been used to enable the decay of short-lived activity and therefore the stored packages tended to contain higher amounts of activity. Finally, a possible factor was that the disposal team may have been aware of the upcoming cessation of disposals and accelerated the rate of disposals for this reason.

2.6. Total volume of waste disposed and volume of the trenches

The total number of trenches at LFBG included trenches 1-77, as well as S1 and S2. There were 55 full length trenches in the two main trenched areas (excluding S1 and S2). There were 14 half-length trenches (equivalent to 7 full length trenches) and 6 trenches which were one-third the full length. Assuming that a full-length trench was nominally 25 m long, then the total trench length in the main trench areas was 64 x 25 m = 1600 metres (plus S1 and S2 of which the dimensions are not exactly known). It should be noted that there is no Trench 13. Furthermore, Trench 77 was apparently not filled with waste, but was backfilled when the site was abandoned.

A total waste volume of 1675 m^3 was given by Isaacs and Mears (1977)[5]. A contemporary inventory in a source document[6] dated 4 September 1968 (which was before the last 2 trenches were filled) gave a total of 1642 m^3. A sum of all the trench waste volumes given in Appendix E yields a value of 1713 m^3. It should be noted that trenches S1 and S2, which were not in the main trenched area contained ~20 m^3 of waste. If we exclude this volume, the total volume disposed in the main trenched area is 1693 m^3. However, the waste volumes in trenches 1-4 were never recorded (note that the length of these only totalled 75 m as T3 and T4 were half trenches). Assuming the waste volumes disposed in the trenches were proportional to their length then the volume of waste disposed in the main trenched areas (i.e. including Trenches 1 to 4) should be increased from 1693 m^3 (in a total length of 1525 m) to 1776 m^3 (corresponding to a total length of 1600 m).

[4] Excluding an apparently accidental entry (which seems to be a typographical error in the EHM) for Trench 10.
[5] This corresponds with the estimate given in Figure 29 (59138 cubic feet).
[6] A minute paper dated 4 Sept 1968 (“Waste Disposal at the Burial Ground”), stated wastes disposed had a total volume of 58000 cubic feet (1642 cubic metres).

The total trench waste volume can be calculated assuming a width of 2 feet (0.6 m) and a filled depth of 2 m (i.e. 1 m of cover). This yields a trench volume of 1600 m X 0.6 m X 2 m = 1920 m^3. A typical 25 m trench therefore had a volume of 30 m^3 (occupied by the waste). The distribution of waste volumes recorded for each trench is shown in Figure 9. The waste volumes are generally consistent with the known trench dimensions. Minor discrepancies may be attributed to trenches being filled higher than usual, or there may have been compression of the waste packages (e.g. fibreboard drums).

Whilst some uncertainties in all of these figures are inevitable, the volumes of wastes and of the trenches are among the better-known quantities associated with the LFBG waste inventories. We suggest a waste volume of 1776 m^3 for the main trenched area (1795 m^3 including S1 and S2) and a corresponding trench volume of 1920 m^3. The small difference is attributed to incomplete trench filling (i.e. voids).

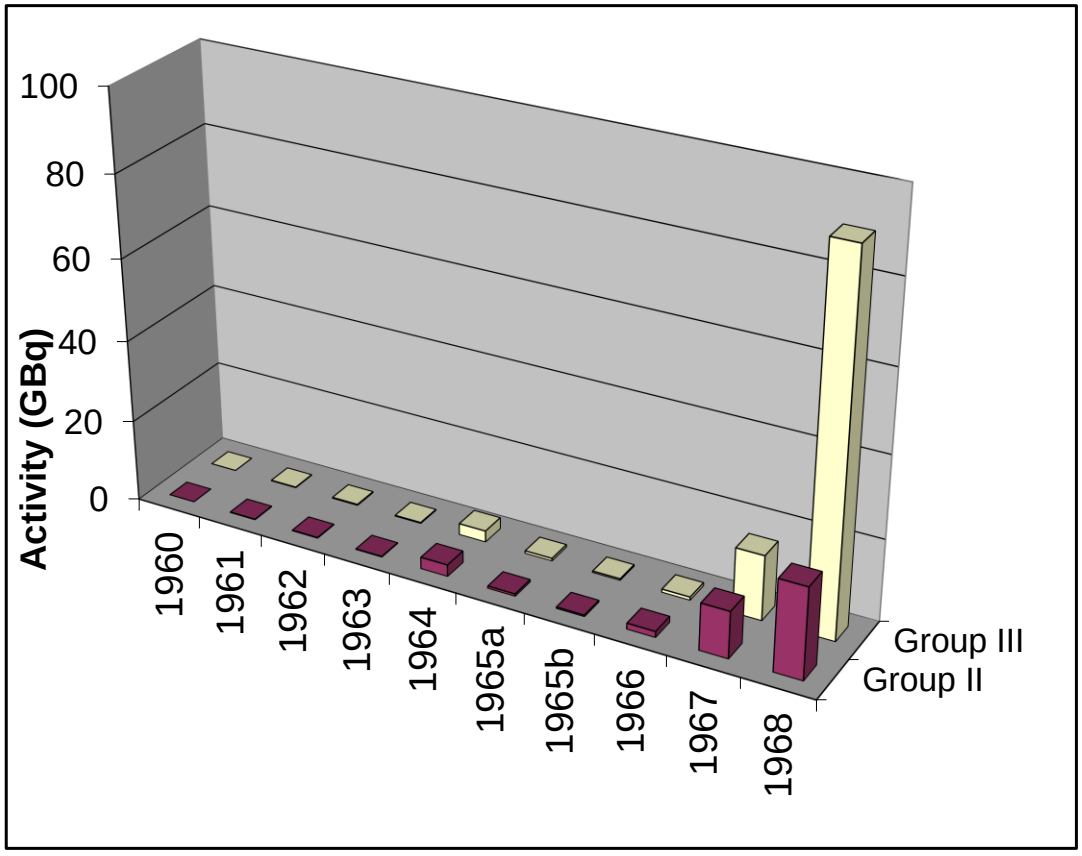


Figure 7. Total activity of Groups II and III radionuclides disposed in each year of operation (based on the EHM document). Note that the activity disposed during 1965 is split into two parts, which were disposed in different parts of the trenched area (see Figure 2). The activity of radionuclides in Group I mostly comprised plutonium (see Figure 8).

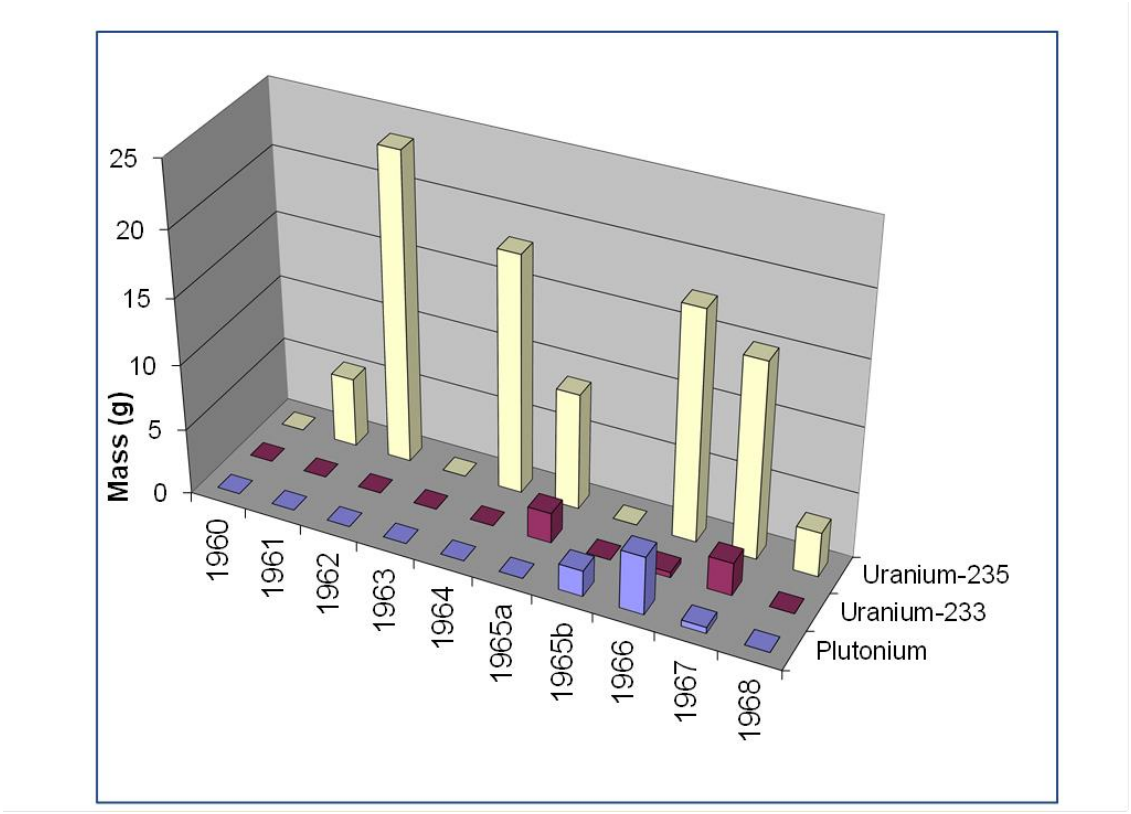


Figure 8. Total mass of fissile isotopes disposed at LFBG for each year of operation (Pu is a member of Group I). The data on actinide disposals presented on this graph was derived from the EHM document and was also published in AAEC (1985).

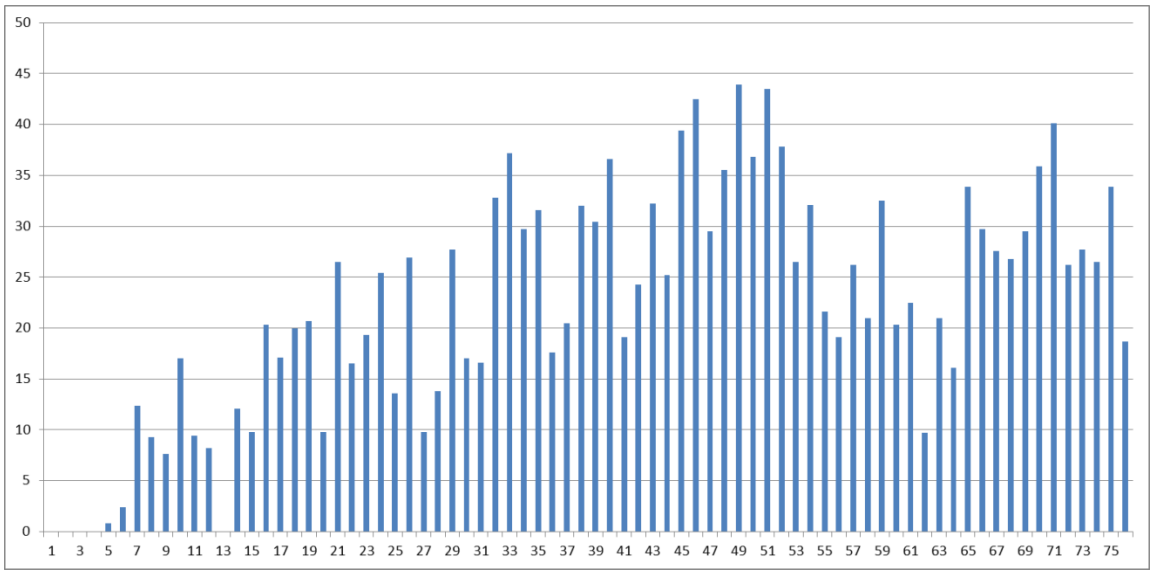


Figure 9. Volume of waste disposed in each Trench, in cubic metres (based on the EHM record). No volumes were recorded for Trenches 1 - 4.

3. Categories of records

The following sections summarise some of the major sources of information about disposals at Little Forest. The order of sections 3.1 to 3.3 reflects the order in which the documents were generated as the waste progressed from originator to disposal (as far as can be determined). When the waste was generated, a pink card was filled out. In some cases, involving materials containing significant quantities of actinides, a "Scrap Disposal Report (SDR)" was completed.

Some of these records had not been examined for many years prior to the investigations described in this report. The SDRs were located in a file at the National Archives of Australia, and the pink cards corresponding to these specific SDR items were found in a storage room at Lucas Heights following many years of being separated from the main set of records. However, many other records (including thousands of pink cards) have not been located and are presumed to have been lost or destroyed.

3.1. The Pink Cards

A few thousand "pink cards" are in existence, described as "Request for Removal of High Level Active or Toxic Materials for Disposal or Storage" and later as "Medium/High Level – Disposal Request". They form a significant proportion of the LFBG records, and for some trenches are the main source of information on disposed items. The existing pink cards mostly relate to the contents of the final few trenches filled. A card was filled out for each package of waste generated by a facility or laboratory and had a unique certificate number. The existing cards have, in most cases, been stored in groups. For many years some sets were stored in bundled paper-wrapped packages (Figure 10). These groups represent (to varying extents) the contents of specific trenches. During the current project, the existing groupings of cards were maintained, but they have been re-housed in plastic storage boxes. In some cases, it was difficult to assign groups of cards to specific trenches with certainty, although this was often possible by cross reference to the waste burial books (or the BGS book). Some waste burial books are shown in Figure 11 (see also section 3.3.2).

The collection of pink cards is fragmentary, and significant numbers of cards only exist for some trenches (e.g. 50-53, 55, 63, 64, 66 and trenches 68 to 76). The estimated numbers of cards for various trenches are summarised in Figure 24 and the accompanying text (full details are in Appendix B). The total number of pink cards is approximately 5000, and therefore they document about 10% of the total number of disposed items.

As discussed above, the waste was categorised according to various descriptors, such as LS (low-level solid), LL (low-level liquid); LSB (low-level solid with beryllium contamination) and LLB (low-level liquid with beryllium contamination). The waste was also assigned a sequential item number, which included the financial year (not the calendar year) in which it was generated.

3.1.1. Information on the front of the pink cards

Typical pink cards are shown in Figure 12 (a liquid waste item) and in Figure 13 (a plutonium contaminated item). The numbered items on the front of the card depicted in Figure 12 are as follows:

1. *Certificate Number:* this was a unique identifier for each package. This number was used to track the waste through the system from storage to disposal. The type of waste was indicated as LL, LSB, etc., with the subsequent numbers being the item number and financial year when the waste was generated. In this example, "LL 37/68" means that this package of waste was the 37th item of Low-Level Liquid Waste for the 1967-68 financial year.
2. *Volume*: this refers to the total volume of the waste. Units are imperial, usually cubic feet or gallons (UK).
3. *The origin of the waste:* identified by building and room number. In principle, this information could be used to infer information on the disposed items, based on the knowledge of the operations undertaken in particular locations.
4. *Container information*: both inner and outer: Types of container included sisalkraft bags, plastic bags and steel drums.

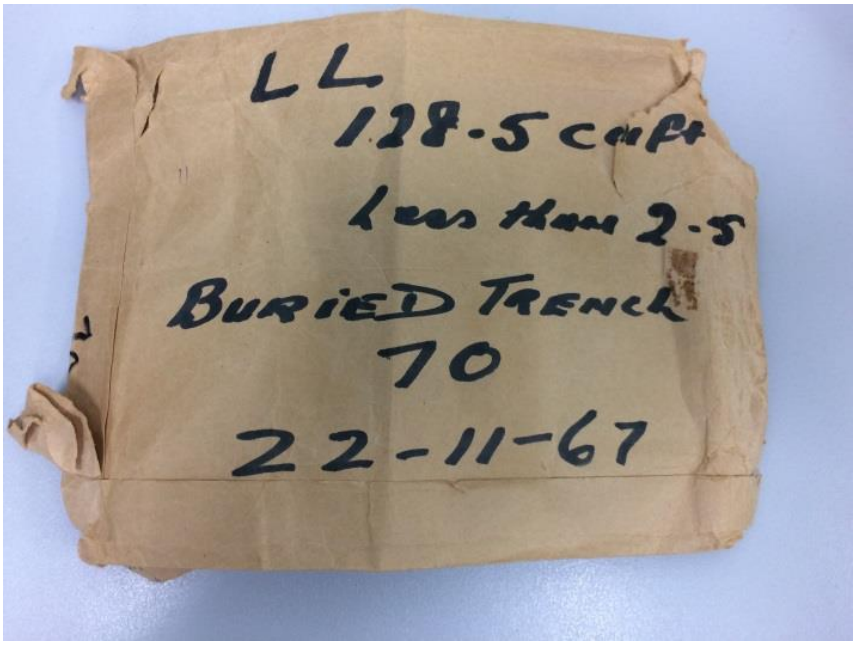


Figure 10. For the final few trenches, there were no summary books, and the pink cards were stored in bundles with labels such as the one shown above.

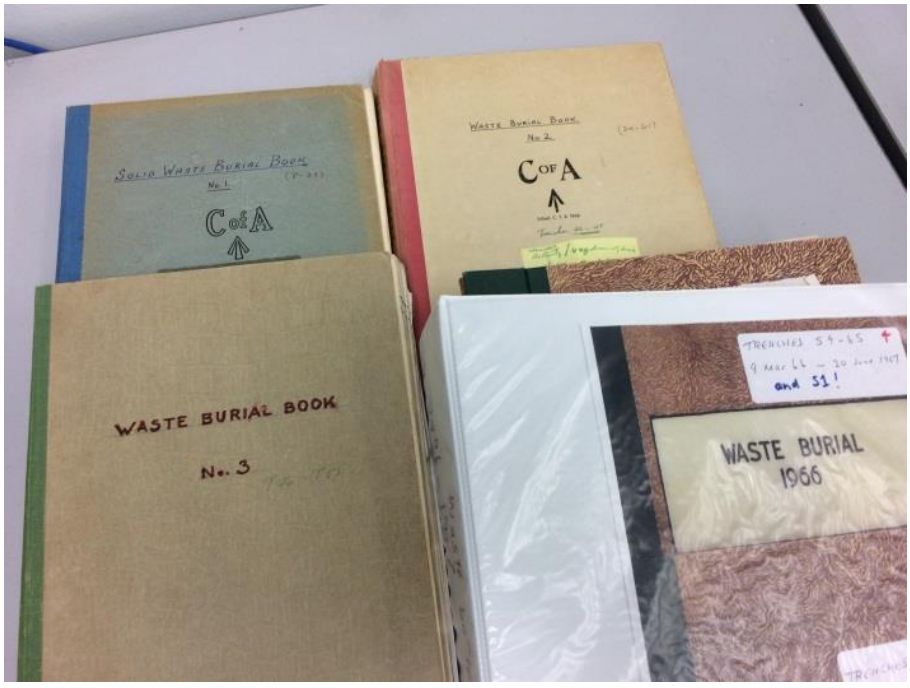


Figure 11. Some of the Waste Burial Books (WBBs). The early burial books were bound notebooks, but later records were kept in loose-leaf folders.

5. *Radiological / Toxicity Information*: this section contains information on the radioisotopes, toxic substances and solvents present in the waste, as well as the maximum activity (in microcuries or millicuries) and dose rate (in mR/hr) of the waste. The information contained in this section was not always specific; for example, it often simply indicated “Mixed Fission Products (MFP)” as the isotopes present, and often reported “Unknown” in some fields, including the activity. This means that, even if the sets of cards were complete, an accurate assessment of the total activity disposed in each trench would not be possible.
6. *General Information:* This section is for a description of the waste, for example, laboratory waste, broken glassware, contaminated equipment, etc. The level of detail varies significantly from descriptive to vague (for example, “trash”).
7. *Signature:* The card was signed by the person requesting the waste removal and disposal. Some signatures are legible. In principle, this information could be useful if it is also known what types of operations were undertaken by specific individuals in particular periods.
8. *Date of disposal request*.
9. *Health Surveyor’s Report:* This section was not always filled out – the conditions when it is required are stipulated on the reverse of the card. It contains instructions from the Health Surveyor regarding handling the waste (for example, “Do Not Open”), their signature and the date of report.

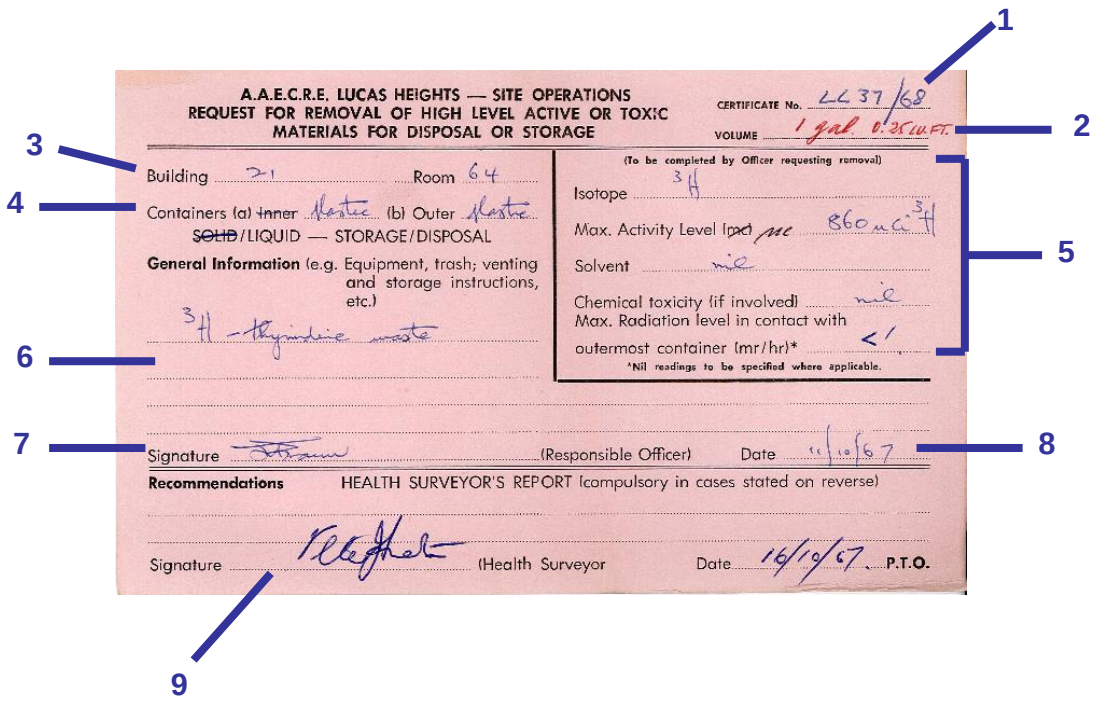
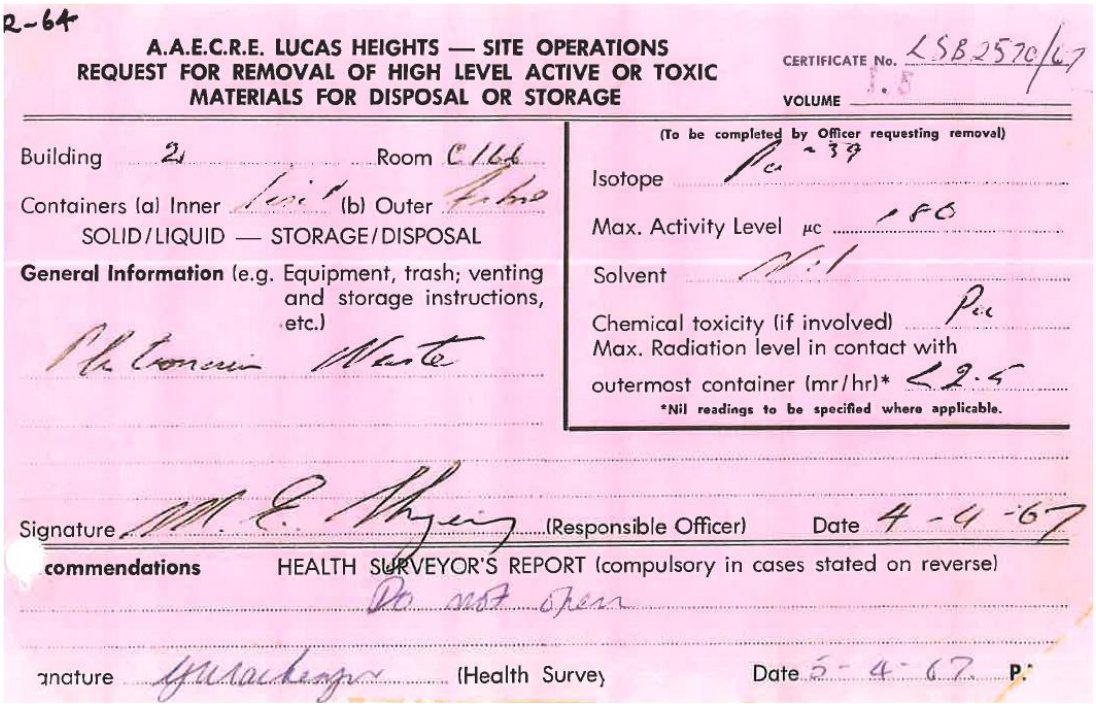


Figure 12. Pink Card for a liquid waste item with numbered descriptors mentioned in the text.



R-64

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. LSB 2570/67
VOLUME 1.5

Building 2 Room C 166
Containers (a) Inner Steel (b) Outer Fibre
SOLID/LIQUID — STORAGE/DISPOSAL
General Information (e.g. Equipment, trash; venting and storage instructions, etc.)
Pu Contam Waste

(To be completed by Officer requesting removal)
Isotope Pu ~ 239
Max. Activity Level μc 180
Solvent Nil
Chemical toxicity (if involved) Pu
Max. Radiation level in contact with outermost container (mr/hr)* < 2.5
*Nil readings to be specified where applicable.

Signature M. E. Thyer (Responsible Officer) Date 4-4-67

commendations HEALTH SURVEYOR'S REPORT (compulsory in cases stated on reverse)
Do not open

gnature (Health Survey) Date 5-4-67 P.

Figure 13. Pink card for a waste item described as "plutonium waste".

3.1.2. Information on the reverse of pink cards

The reverse side of a pink card is shown in Figure 14. The information included:

1. *Disposal Instructions:* This section sometimes included a description of how the waste was to be stored and subsequently disposed. Often, as in the example in Figure 14, it was left blank. A number of records have a burial date indicated on them, while others also include the number of the disposal trench. The upper part of the card includes a section for a signature, presumably of the relevant waste operations supervisor.
2. *Storage Details:* This section included information on the storage and subsequent movements of the waste (including dates of removal, new location, etc.). This was almost always left blank. There is space for two signatures, but it is not clear who would have signed off on this section.
3. *Health Surveyor's Report*: This section stipulated the conditions for which a Health Surveyor's Report was necessary.

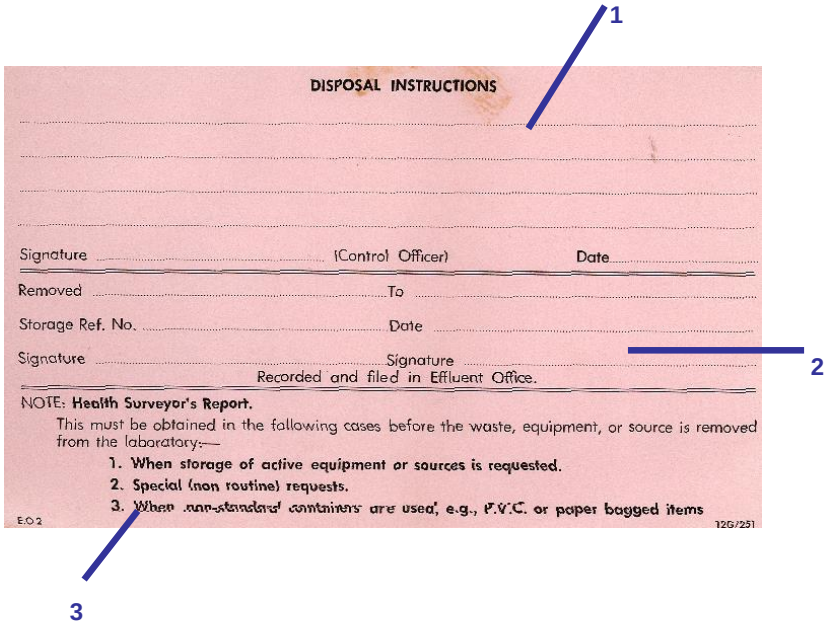


Figure 14. Reverse side of a pink card.

3.2. Scrap disposal reports (SDRs)

The Scrap Disposal Reports (SDRs) are an extremely important set of records, because they contain the original information used to compile the inventories of fissile materials (Plutonium, U-233, U-235), reported in the previous disposal summaries (for example, they are the source of the data shown in Figure 8 and published in an AAEC report put on the public record in the mid 1980s (AAEC, 1985)).

The SDRs were apparently used to compile the WBRs (Section 3.4), which appear to be the source for all subsequent tabulations of LFBG wastes (including the EHM document). The SDRs were similar to the pink cards in that each of them referred to a single item (or a small number of items), however a major difference was that only 104 SDRs were produced in the entire disposal period of LFBG (during which nearly 50,000 items were disposed at the site). The SDRs were only created for items considered to have a significant content of fissile / fertile isotopes. The first SDR for an item known to have been disposed at LFBG was SDR #2 containing 0.9 Kg of thorium buried in Trench 12.

At some point, the SDRs were collected for safe-keeping and eventually transferred to the National Archives, where they remained for some decades until re-located during the present project. Each SDR has been photocopied and the copy put on an ANSTO file[7], and there is also an electronic version (pdf) of these significant documents. A full summary of the items and the isotopes recorded in the SDRs is provided in Appendix F.

The SDRs were sequentially numbered, and it appears that SDRs #2 to #104 refer to items generated during the operational period of the LFBG (SDR #1 is missing as well as #54, #55 and #63). Some of these SDRs relate to items which were actually buried at LFBG, whereas others had not been buried at the time of cessation of burial operations and were subsequently stored elsewhere. The fate of a few of the SDR items (or in some cases packages within the consignment of items covered by an SDR) is not definitively known. A summary of the disposition of items in SDRs is given in Table 1. This Table shows that the radionuclide content of items processed in the water treatment plant (e.g. #8, #10, #22, and possibly #74) effectively became unaccounted for, and was omitted in the estimation of the inventory (although it should have been considered as part of the disposed sludges originating from the plant). This is an important finding for a number of reasons. In particular, it provides evidence that the radionuclide content of the sludges may be a significant component of the LFLS inventory.

[7] The originals remain in the National Archives

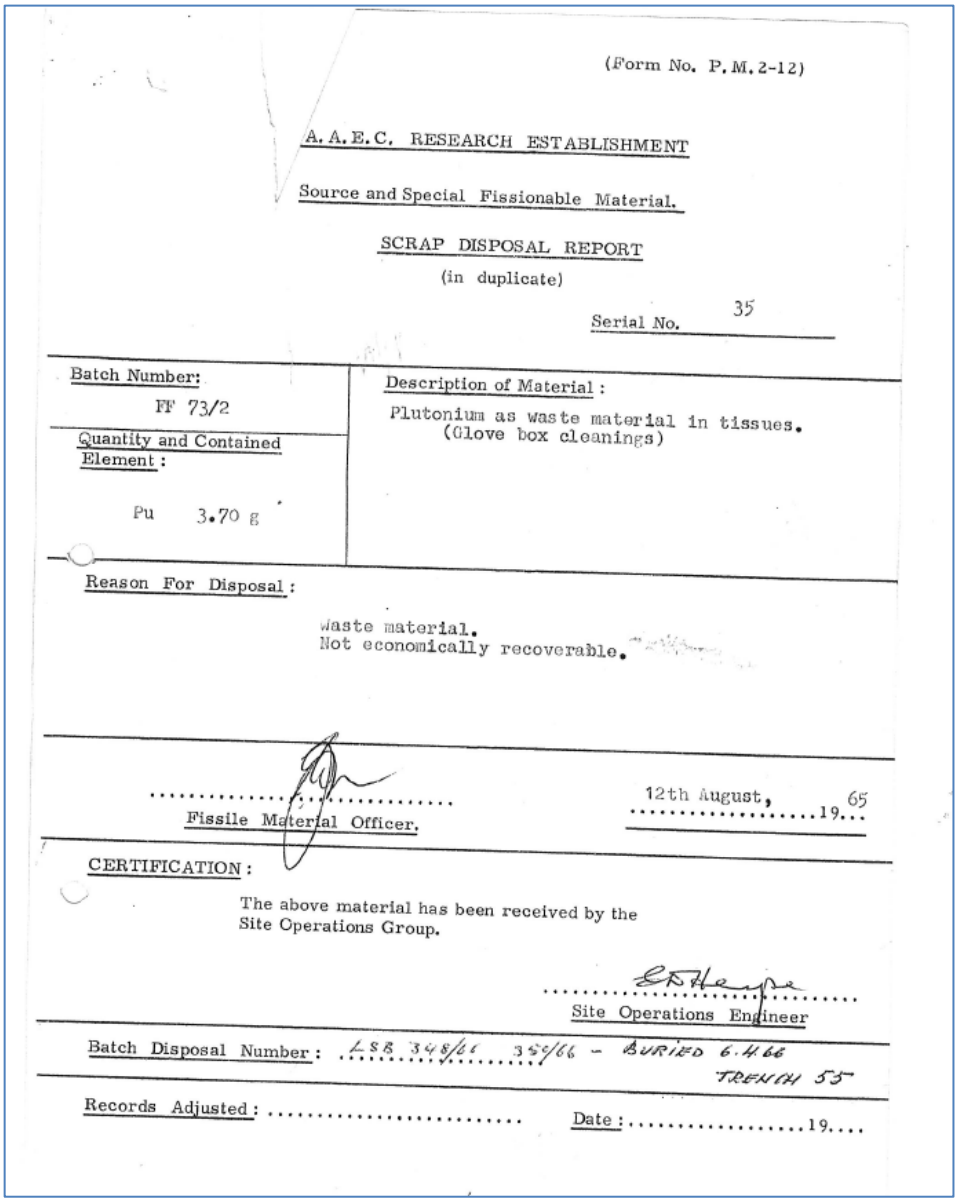
Table 1. Ultimate fate of SDR items #1 to #104 (see also Appendix F).

Fate of SDR items	Number of items	Comment
Buried in trenches	68	Accounted for in available trench disposal summary records (e.g. WBRs, EHM, AAEC (1985)).
Processed in water treatment plant (SDR #8, #10, #22)	3	These items all contained U-235 (a total of ~20 g) and would eventually have contributed to the U-235 content of the sludge drums buried at LFBG (which contained sludges from the water treatment plant). As discussed elsewhere in this report, the Group I radionuclide content of the sludges was not accounted for (except in the final year of disposals) and has not been previously included in summary documents.
Presumed buried (SDR #30, #68)	2	Have not been included in the inventory (but arguably should be added).
Missing / unknown fate (SDR #1, #54, #55, #63, #74)	5	Neither the radionuclide content nor the fate of these items can be deduced.
Long term storage	26	Not included in LFLS inventory.

An example of an SDR for a major Pu-contaminated item is given in Figure 15. The waste is described as “plutonium as waste materials in tissues (glove box cleanings)”. It is not known how the Pu content was measured.

The item in Figure 15 is the larger of two Pu-contaminated items, which were eventually buried in Trench 55, and comprise over half the entire recorded Pu inventory of the LFBG. In fact, over 90% of the Pu reportedly buried at the site was from just three SDR items. Thus, the reliability of the estimated amount of Pu disposed at LFLS is dependent on the completeness and accuracy of a very small number of the SDR records. Conversely, the other items disposed at LFLS (approximately 50,000) must be assumed to contribute a negligible amount to the Pu inventory in order for the estimates of total Pu disposals to be considered reliable (it is probable that the majority of these items did not contain significant amounts of Pu). However, glove-boxes (such as the one mentioned on this SDR) were in operation at Lucas Heights during the disposal period in the 1960s, and it is therefore possible that other glove-box cleaning operations occurred, during which the Pu removed was either not documented or the documentation has been lost.

The inventory of U-233 buried is similarly dependent on a small number (~4) of SDRs, which account for the entire reported inventory at LFBG. An example of an SDR for U-233 is given in Figure 16. The item is described as “high level”. Although this does not correspond to the definitions in modern usage, it flags an item of significant activity. The item shown in Figure 16 was buried in Trench 67 and given a batch disposal number of F6/68 (F = fissile). Appendix C shows that trench 67 contained at least 9 “F” items. However, the pink cards for these items are not available (Appendix B records nil pink cards for Trench 67, also see Figure 24).



(Form No. P.M.2-12)

A.A.E.C. RESEARCH ESTABLISHMENT

Source and Special Fissionable Material.

SCRAP DISPOSAL REPORT

(in duplicate)

Serial No. 35

Batch Number:	Description of Material :
FF 73/2	Plutonium as waste material in tissues. (Glove box cleanings)
Quantity and Contained Element :	
Pu 3.70 g	

Reason For Disposal :

Waste material.
Not economically recoverable.

..... 12th August, 65
Fissile Material Officer. .....19...

CERTIFICATION :

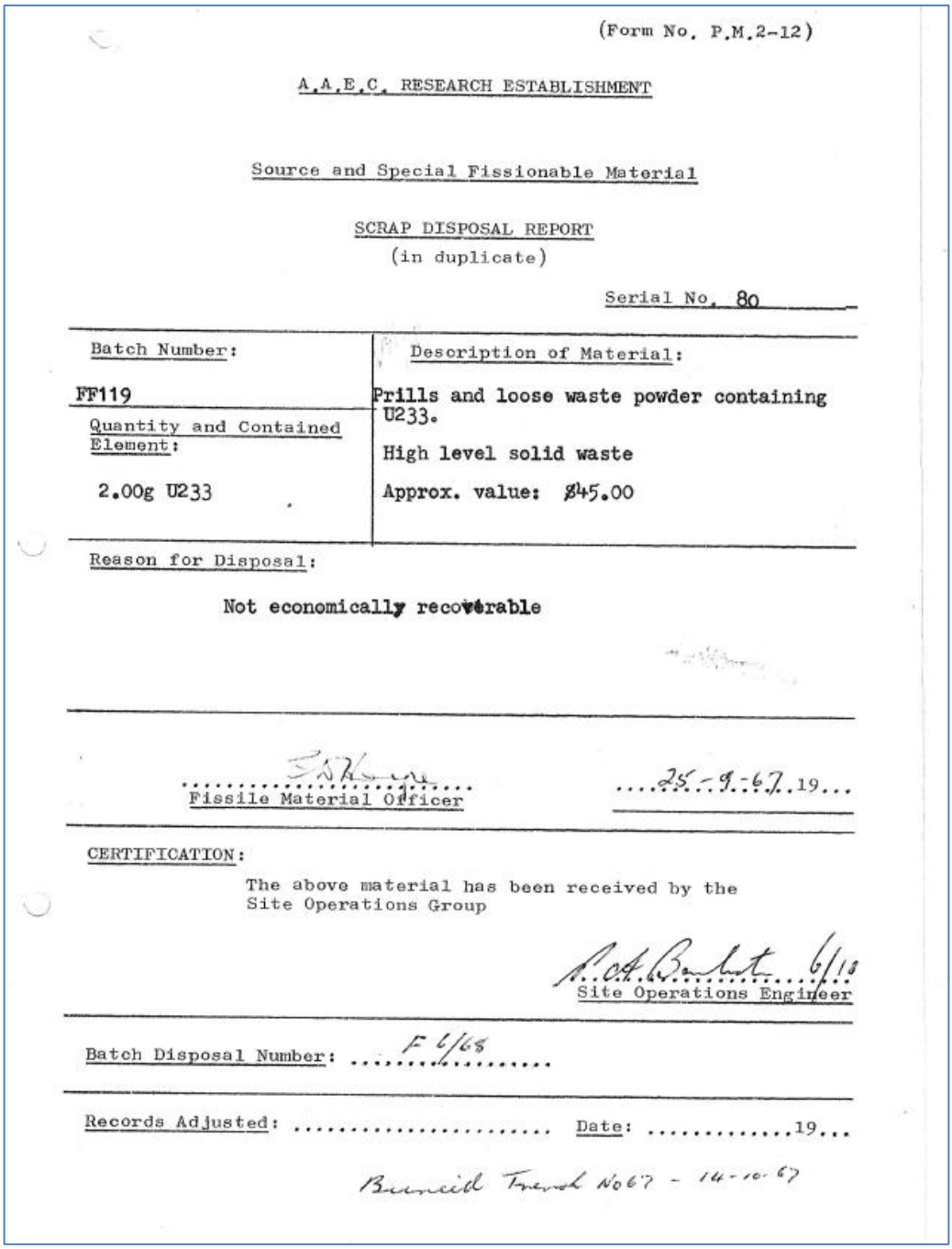
The above material has been received by the Site Operations Group.

.....
Site Operations Engineer

Batch Disposal Number : LSB 348/66 356/66 - BURIED 6.4.66 TRENCH 55

Records Adjusted : ..... Date : .....19....

Figure 15. SDR 35, recording 3.70 g of Pu which was eventually buried in Trench 55. This is the largest single known burial of plutonium at LFBG.



(Form No. P.M.2-12)

A.A.E.C. RESEARCH ESTABLISHMENT

Source and Special Fissionable Material

SCRAP DISPOSAL REPORT
(in duplicate)

Serial No. 80

Batch Number:	Description of Material:
FF119	Prills and loose waste powder containing U233.
Quantity and Contained Element:	High level solid waste
2.00g U233	Approx. value: $45.00

Reason for Disposal:

Not economically recoverable

Fissile Material Officer ..... 25-9-67 19...

CERTIFICATION:

The above material has been received by the Site Operations Group

Site Operations Engineer 6/10

Batch Disposal Number: F 6/68

Records Adjusted: ..... Date: .....19...

Buried Trench No 67 - 14-10-67

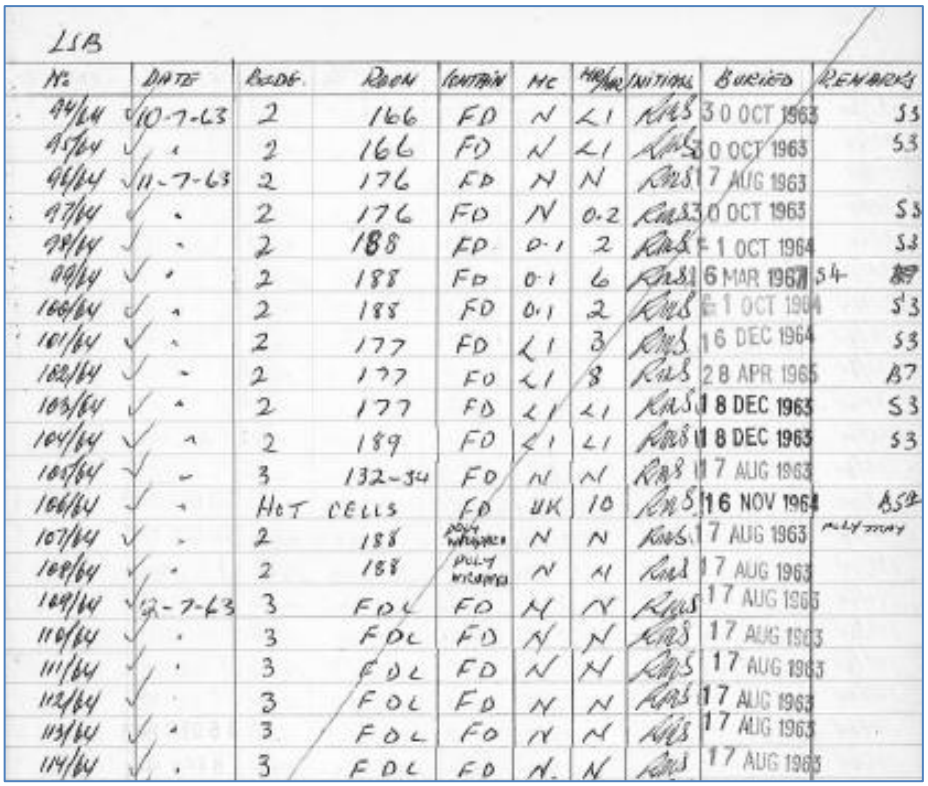
Figure 16. SDR 80 for 2.00 g of U-233 buried in Trench 67, described as "high level solid waste". This single item contains nearly 40% of the stated U-233 at LFBG and is one of only four known U-233 items, which together constitute the entire reported inventory of U-233 at the site.

3.3. Waste record books

3.3.1. Waste log books

It is assumed that these books were used to keep records of waste packages as they were received by waste operations. The details of each package were recorded sequentially in these books (Figure 17). The information included the assigned number, date, location of waste generation, type of container, estimated activity, external dose-rate and date buried (if known). This latter date can usually be matched to the specific trench which was being filled at the time.

However, the set of these books is clearly not complete. The only books available are numbered 2, 4, 6, 7, 8, 9, and 10, which mostly contain information on LSB wastes from 1961 to 1968 (for example, the 7th LSB book reported items LSB 1/65 to LSB 4017/65 received during the 1965 financial year). The LS waste type is only listed in book 2 (i.e. items from 1960 to 1962). Similar record books for other types of wastes have not been located. Due to the fragmentary nature of this set of records, this source has provided very little usable information for the present survey.



LSB

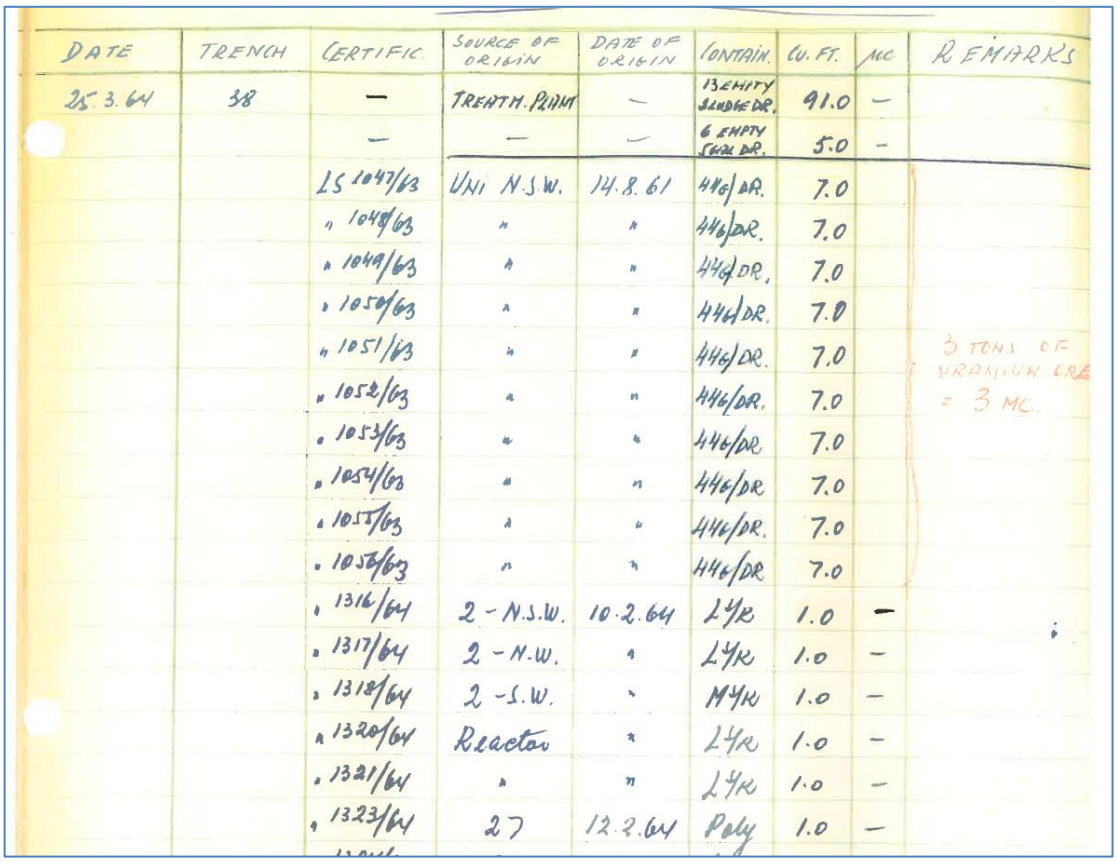
No.	DATE	BLDG.	ROOM	CONTAIN	WC	WEIGHT	INITIALS	BURIED	REMARKS
94/64	10-7-63	2	166	FD	N	<1	KMS	30 OCT 1963	S3
95/64	"	2	166	FD	N	<1	KMS	30 OCT 1963	S3
96/64	11-7-63	2	176	FD	N	N	KMS	17 AUG 1963	
97/64	"	2	176	FD	N	0.2	KMS	30 OCT 1963	S3
98/64	"	2	188	FD	0.1	2	KMS	1 OCT 1964	S3
99/64	"	2	188	FD	0.1	6	KMS	6 MAR 1967	S4
100/64	"	2	188	FD	0.1	2	KMS	1 OCT 1964	S3
101/64	"	2	177	FD	<1	3	KMS	16 DEC 1964	S3
102/64	"	2	177	FD	<1	8	KMS	28 APR 1965	B7
103/64	"	2	177	FD	<1	<1	KMS	18 DEC 1963	S3
104/64	"	2	189	FD	<1	<1	KMS	18 DEC 1963	S3
105/64	"	3	132-34	FD	N	N	KMS	17 AUG 1963	
106/64	"	HOT CELLS		FD	UK	10	KMS	16 NOV 1964	B52
107/64	"	2	188	[illegible]	N	N	KMS	17 AUG 1963	POLY-VINYL
108/64	"	2	188	POLY WRAPPED	N	N	KMS	17 AUG 1963	
109/64	12-7-63	3	FDL	FD	N	N	KMS	17 AUG 1963	
110/64	"	3	FDL	FD	N	N	KMS	17 AUG 1963	
111/64	"	3	FDL	FD	N	N	KMS	17 AUG 1963	
112/64	"	3	FDL	FD	N	N	KMS	17 AUG 1963	
113/64	"	3	FDL	FD	N	N	KMS	17 AUG 1963	
114/64	"	3	FDL	FD	N	N	KMS	17 AUG 1963	

Figure 17. Extract from solid waste log book (No. 6) for LSB wastes showing sequential arrival of packages and various eventual burial dates.

3.3.2. Solid waste burial books (WBBs)

These large foolscap-sized books (Figure 11) were used to record the contents of each trench at LFBG. Waste was not buried in the order of generation but according to decisions regarding its activity and possibly other (unknown) considerations. An example of a WBB is the extract from the burial record for Trench 38 shown in Figure 18. The information includes the date of filling, trench number, the item numbers disposed, the sources of the wastes, the date of generation, the type of container, volume, activity (if recorded) and remarks. These books are an important source of information, because they contain an almost complete record of disposals from Trench 6 until Trench 68.

The coverage of specific trenches by the solid waste burial books is summarised in Table 2. However, the information on the first 6 trenches is almost non-existent. For example the content of Trench 2 is reported on a small scrap of paper (Figure 19).



DATE	TRENCH	CERTIFIC.	SOURCE OF ORIGIN	DATE OF ORIGIN	CONTAIN.	CU. FT.	MC	REMARKS
25.3.64	38	—	TREATM. PLANT	—	13 EMPTY SLUDGE DR.	91.0	—	
		—	—	—	6 EMPTY SLUDGE DR.	5.0	—	
		LS 1047/63	UNI N.S.W.	14.8.61	44G/DR.	7.0		
		" 1048/63	"	"	44G/DR.	7.0		
		" 1049/63	"	"	44G/DR.	7.0		
		" 1050/63	"	"	44G/DR.	7.0		
		" 1051/63	"	"	44G/DR.	7.0		3 TONS OF URANIUM ORE = 3 MC.
		" 1052/63	"	"	44G/DR.	7.0		
		" 1053/63	"	"	44G/DR.	7.0		
		" 1054/63	"	"	44G/DR.	7.0		
		" 1055/63	"	"	44G/DR.	7.0		
		" 1056/63	"	"	44G/DR.	7.0		
		" 1316/64	2 - N.S.W.	10.2.64	44/K	1.0	—	
		" 1317/64	2 - N.W.	"	44/K	1.0	—	
		" 1318/64	2 - S.W.	"	M44K	1.0	—	
		" 1320/64	Reactor	"	44/K	1.0	—	
		" 1321/64	"	"	44/K	1.0	—	
		" 1323/64	27	12.2.64	Poly	1.0	—	

Figure 18. Extract from waste burial book (for Trench 38). The waste in these books is grouped by disposal trench.

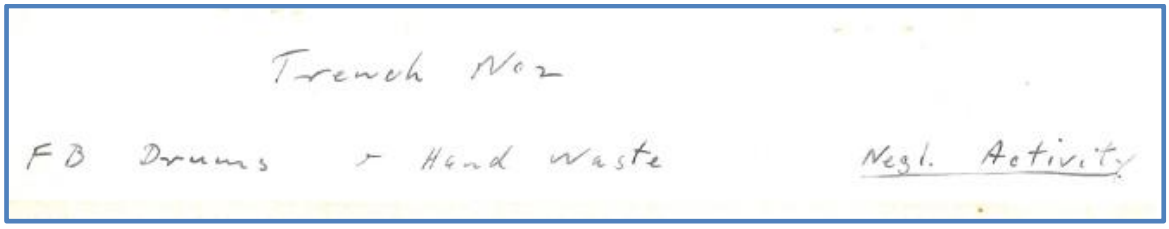


Figure 19. Reported contents of Trench 2 were "FB" (fibreboard) drums and "hand waste" with negligible activity.

Table 2. Coverage of waste burial books. Note that WBB-4 and WBB-5 are in loose-leaf binder format.

Book	Trenches	Notes
WBB-1	1 to 29	From 1960 to 18 April 1963. Little information for trenches 1 to 6.
WBB-2	29 to 45	From 18 April 1963 to 16 Nov 1964. Lists items burned in a pit (or possibly different pits) on 26 May 1964, 31 August 1964 and 4 September 1964.
WBB-3	46 to 53	From 16 Dec 1964 to 23 Dec 1965.
WBB-4	54 to 65, and S1	Titled: “Waste burials 1966”
WBB-5	66 and 67	“Waste Burials 1967”
Missing	68 to 76, and S2	There is no burial book for these trenches, although some pink cards exist.

3.3.3. Burial ground store (BGS) book

This is a similar style of notebook to the waste log books. The BGS book contains an inventory of material at the burial ground store (as of 17 August 1967) and some items added after that date (these items were mostly disposed in Trenches 67 to 70). The information in this book is very fragmentary, with somewhat better coverage of Trench 67, which was filled soon after the items were recorded in this book. Unfortunately, there is no similar record for Trenches 71 to 76, which presumably included items which arrived on the LFBG site after the BGS book was compiled.

3.4. Waste burial records (WBRs)

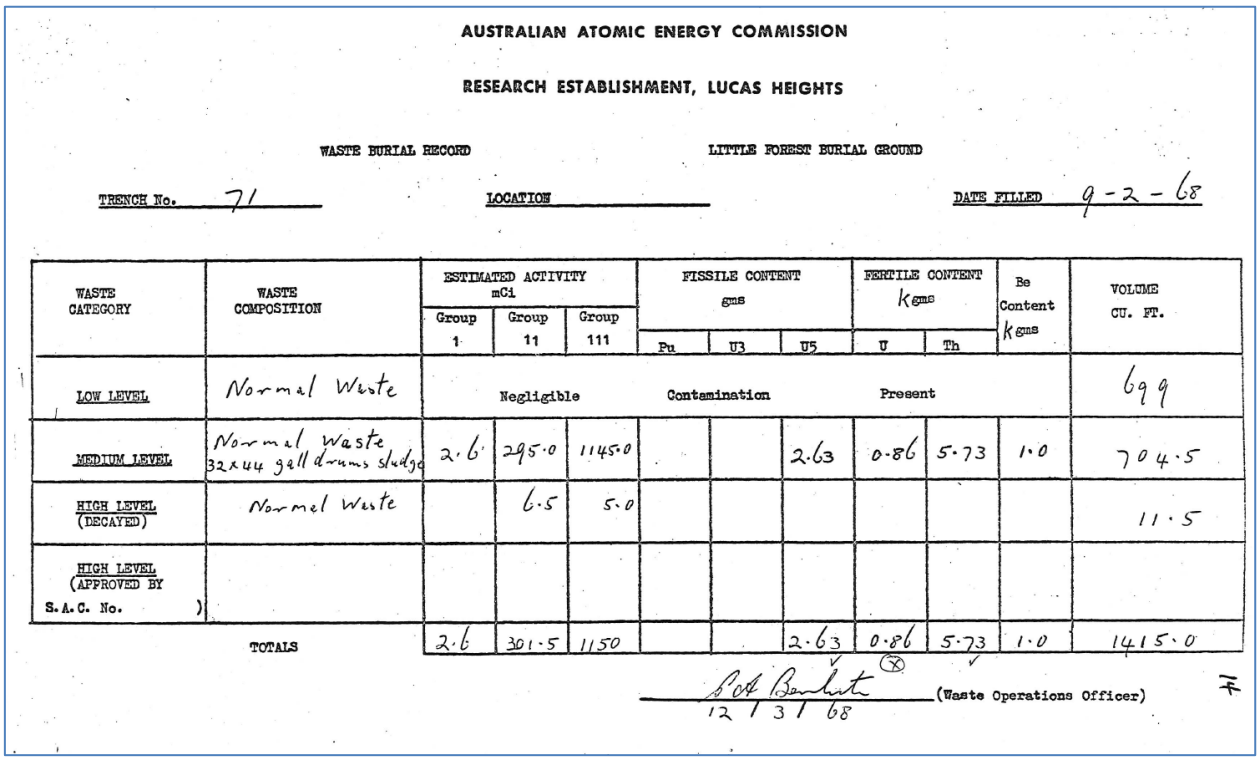
This is a set of single-page records, each summarising the contents of a single trench. The WBRs are stored on ANSTO files, and copies have been saved in the LFBG digital archive. Based on the dates of these records, the first WBR record actually completed was for Trench 71. This trench had been filled on 9 Feb 1968 and the record was completed on 12 March 1968 (Figure 20). The WBRs for Trenches 72 to 76 were completed within about a month of the corresponding burials in 1968. The WBRs for the earlier trenches (7 to 70) were retrospectively completed between 20 August and 23 August 1968 by P.A. Bonhote (Waste Operations officer). Thus, these WBRs were all completed within a relatively short period, several years after the earlier trenches were filled.

It appears that the WBRs were the main source of information for all subsequent compilations, including the key EHM report (see below). The rapid completion of the WBRs (and the delay, often several years, between the trench disposals and the completion of the WBRs) suggests that caution should be applied when interpreting these documents. In fact, it will be shown below that the beryllium disposals (at least) were probably estimated using a “rule-of-thumb” approximation, and there is conclusive evidence that the Fissile / Fertile EHM inventory considered only the information in the SDRs (discussed below). As noted above, the SDRs only cover a small number of items (~100 of the 50000 disposed).

The WBRs included various categories of wastes with the rows labelled

- Low level (usually corresponded to LS items).
- Medium Level (often LSB items).
- High level (decayed), which appears to have been items stored in the burial ground hut for some period. Items in this category were only disposed in trenches 71, 74, 75 and 76.
- High level items approved for disposal by the safety assessment committee (SAC). Items in this category were only disposed in Trench 73 (a batch of items containing dispersible beryllium – see Sections 7.5 and 8.10.2).

Note that the term “High level” differed significantly from the modern meaning which usually implies high activity heat generating waste. This term was not used in summary documents such as the EHM.



AUSTRALIAN ATOMIC ENERGY COMMISSION

RESEARCH ESTABLISHMENT, LUCAS HEIGHTS

WASTE BURIAL RECORD — LITTLE FOREST BURIAL GROUND

TRENCH No. 71 — LOCATION — DATE FILLED 9-2-68

WASTE CATEGORY	WASTE COMPOSITION	ESTIMATED ACTIVITY mCi Group 1	Group 11	Group 111	FISSILE CONTENT gms Pu	U3	U5	FERTILE CONTENT Kgms U	Th	Be Content Kgms	VOLUME CU. FT.
LOW LEVEL	Normal Waste	Negligible			Contamination			Present			699
MEDIUM LEVEL	Normal Waste 32x44 gall drums sludge	2.6	295.0	1145.0			2.63	0.86	5.73	1.0	704.5
HIGH LEVEL (DECAYED)	Normal Waste		6.5	5.0							11.5
HIGH LEVEL (APPROVED BY S.A.C. No.)											
TOTALS		2.6	301.5	1150			2.63	0.86	5.73	1.0	1415.0

(Waste Operations Officer)

12/3/68

Figure 20. Waste burial record (WBR) for Trench 71.

3.5. Documents obtained from ANSTO records and National Archives of Australia

During the course of the research project, a large number of documents (including memos, letters, reports, etc.) pertaining to the LFBG were obtained from various repositories of information, primarily ANSTO records section and the National Archives of Australia. Typically, these were collected from AAEC files which were organised according to particular topics and projects, and contained various documents relating to these activities. Copies of all relevant documents obtained from these sources have been stored electronically[8] and also saved on paper files[9]. Various information derived from these collections is mentioned throughout the present report and other related reports. Some of the information relating to inquiries and deliberations after the disposal period is discussed in Chapter 10 of this report.

The number of documents concerning the LFBG provides qualitative information about the amount of effort dedicated by senior AAEC management into supervision and oversight of the operations at LFBG. This archival record reflects both the amount of effort being devoted to managing the disposals, as well as the extent to which the documents were preserved. As shown in Figure 21, a number of documents were generated during the site assessment period (before 1960). However, only a relatively small number of documents are available for the operational period (excluding numerous operational items such as burial books and pink cards). The small number of surviving documents from the operational period mainly concern waste disposals at LFBG for external organisations (Section 7.6). It may be inferred that the operation of LFBG was subject to limited oversight from senior management during the majority of the disposal years. In the final year of LFBG operations (1968) the trench disposals became subject to much closer scrutiny.

[8] ANSTO has a regularly backed up digital file system.

[9] Paper files are stored by ANSTO records section.

In 1968, numerous issues associated with the disposals arose, which led to extensive discussions within the senior management of AAEC and to the eventual closure of the site. These concerns resulted in a peak in the graph in 1968 (Figure 21), which represents the discussions of topics including appropriate waste containment and management concerns regarding the LFBG disposal operations (see Sections 7.7 to 7.11). A later peak of interest around 1973 was mainly concerned with the possibility of re-opening the LFBG site for more disposals (see (Ellis, 1977)), however enthusiasm for this proposal eventually dissipated.

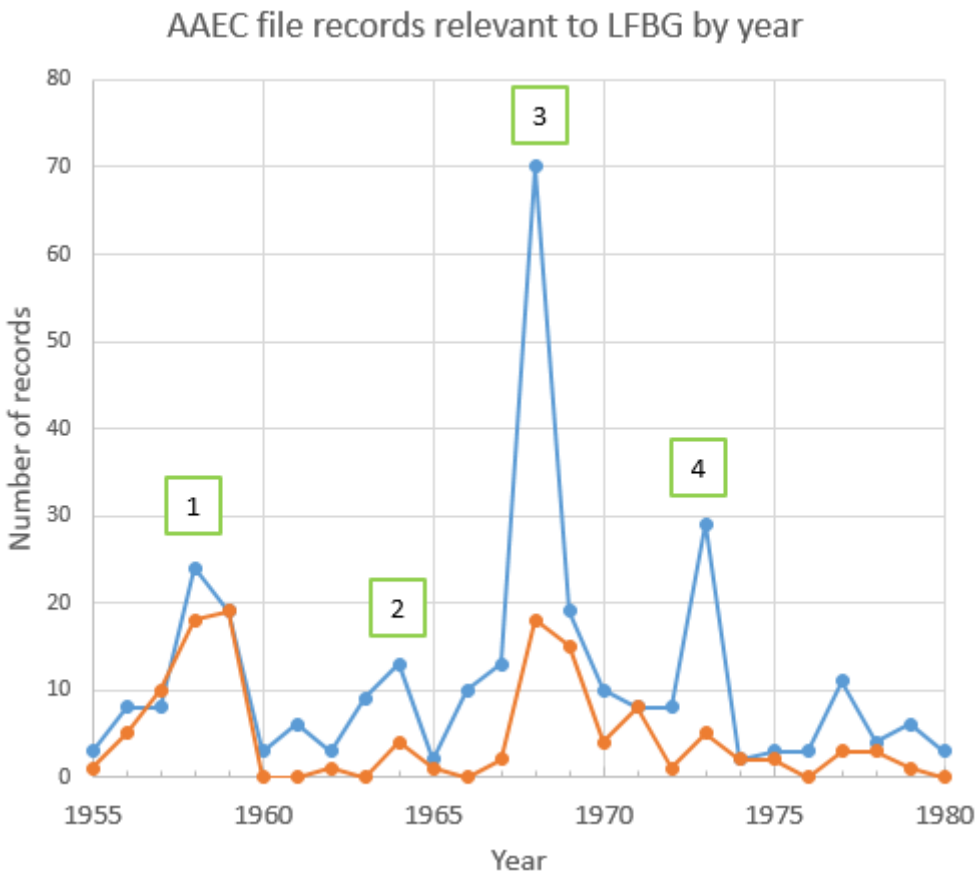


Figure 21. Distribution of records relevant to LFBG disposals found during this project (blue) and those summarised in an earlier survey undertaken in 1983 (orange). Peak 1 is the site evaluation phase. Peak 2 reflects discussions of waste disposals for outside organisations. Peak 3 is mostly derived from discussions of senior management which led to the cessation of disposals. A later peak (4) resulted from evaluation of the possibility of re-opening the site for more disposals (this proposal was eventually abandoned).

4. Summary of records of disposed items

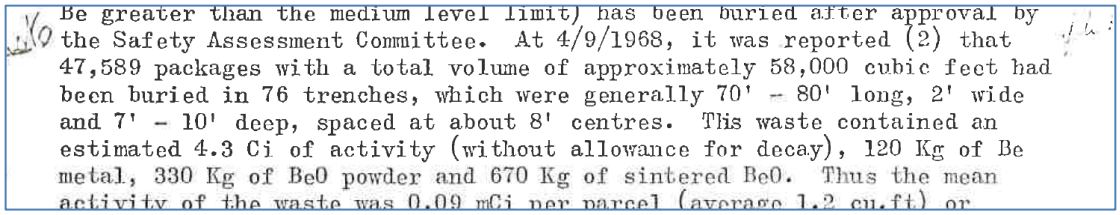
4.1. Items recorded in waste burial books and burial ground store book

As noted above, the Waste Burial Books (WBBs) are the most complete overview record of the individual items buried at the LFBG. These books contain key types of information, including origin, container type, volume, and activity levels. However, they lack the level of detail recorded on the original pink cards, such as the isotopes present and the form of the waste.

The burial books also contain summary sheets, collating the total volume and activity reported for each trench. This is valuable information regarding the contents of each trench, particularly given that the coverage is much more complete than the pink cards. However, the WBBs are themselves incomplete, with the WBBs for Trenches 1-6, and from Trench 68 onwards, all missing. The WBBs (plus some information from the burial ground store (BGS) book) seem to be the most reliable documents in terms of unambiguously assigning items to specific trenches and burial dates, but the WBBs do not include any information about trenches 68 to 76 (and S2). Sets of pink cards exist for these trenches, but these appear to be incomplete.

It is a relatively straightforward exercise (although laborious) to count the number of items recorded in the burial books and assign them to various waste categories. These data are summarised in Appendix C and the total item counts are shown in Figure 23. The number of packages in each trench would be expected to be variable, depending on the trench length and the volume of individual items, but some variations can be attributed to data gaps.

A total of over 36,000 item disposal records have been located in the waste burial books and associated documents. Another 1503 cards have been identified for wastes buried in trenches 71 to 76, which are not recorded in any WBB. Considering the number of items typically disposed in a trench (approximately 800), it is likely that these 6 trenches contained many items beyond those for which pink cards exist (likely reduced to some extent by the presence of the larger sludge drums). To this would be added an unknown number of items in several trenches for which documentation has been entirely lost (e.g. trenches 1 to 5, and trench S2), as well as items without documentation at the time of disposal. In addition, a number of trenches may not have complete inventories in the burial books. For example, trenches 67 had items reported in both the WBB and BGS book, however for trenches 68 to 70 only the BGS book is available. Clearly there could be several thousand additional items. As a result, the early estimate of 47600 packages (Isaacs and Mears, 1977) seems reasonable. It is likely to be a slight underestimate, as it appears to be very similar to number given in the extract shown below (Figure 22) in which the items in the final two trenches (yet to be filled at that time) were excluded from the item count. Thus, a round figure of 50,000 items is probably applicable. The key issue is not so much whether the number of items is accurate. Much more important is the question of whether the missing documentation contains significant items which should be given special consideration, or simply more items similar to those for which documentation exists.



Be greater than the medium level limit) has been buried after approval by the Safety Assessment Committee. At 4/9/1968, it was reported (2) that 47,589 packages with a total volume of approximately 58,000 cubic feet had been buried in 76 trenches, which were generally 70' - 80' long, 2' wide and 7' - 10' deep, spaced at about 8' centres. This waste contained an estimated 4.3 Ci of activity (without allowance for decay), 120 Kg of Be metal, 330 Kg of BeO powder and 670 Kg of sintered BeO. Thus the mean activity of the waste was 0.09 mCi per parcel (average 1.2 cu.ft) or

Figure 22. Extract from a contemporary document (dated 29 Nov 1968) indicating that 47,859 packages were buried until 4 September 1968. This estimate excludes trenches 75 and 76 which were the last trenches filled (in November 1968).

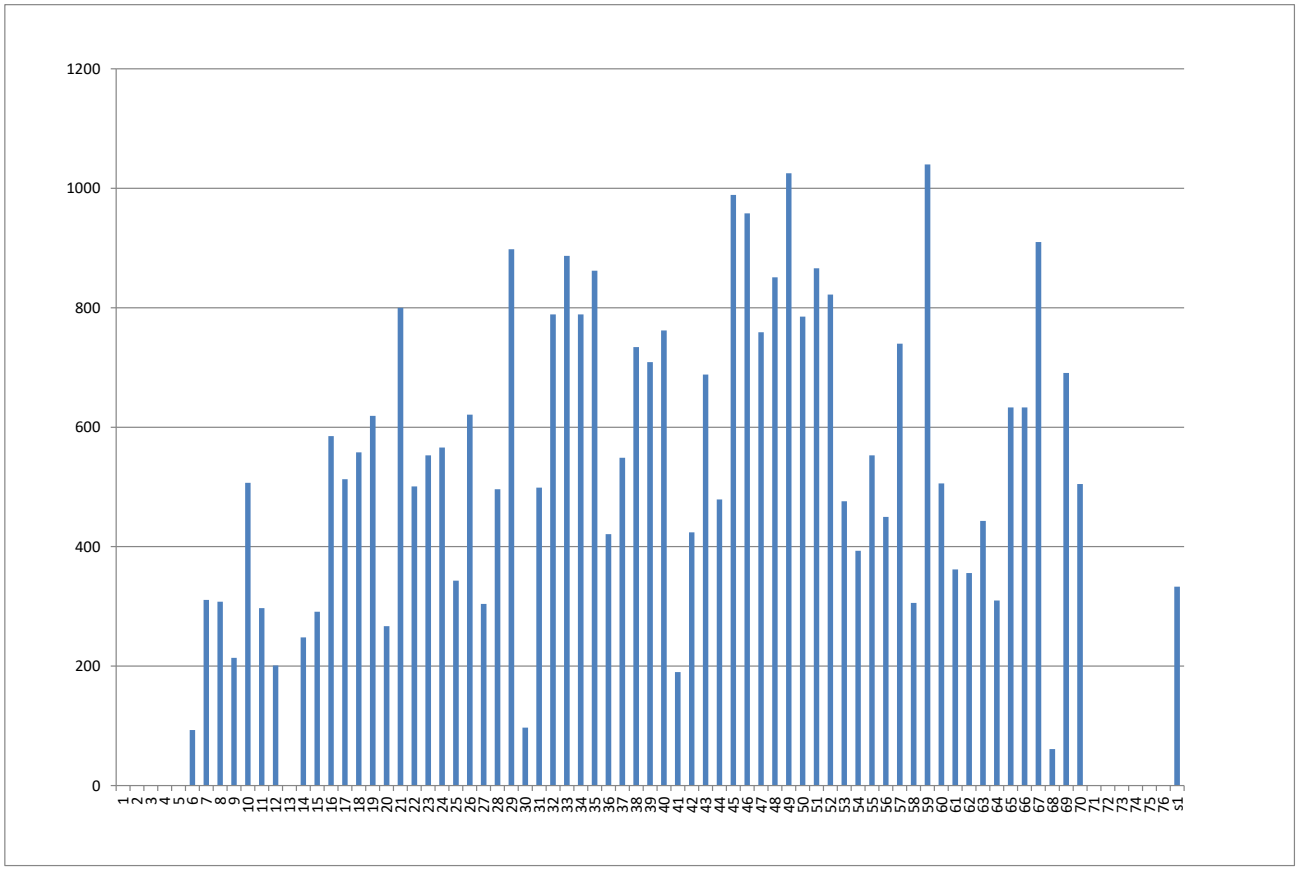


Figure 23. Distribution of number of items by individual trenches as recorded in the WBBs and BGS book. Data are missing for the early trenches (1-5) as well as Trenches 71 to 76 and S2 (S1 is shown at the extreme right of the figure). Some waste items were burnt in Trench 13 (there are a small number of pink cards for these items), but its location is unknown.

4.2. Items for which pink cards have been preserved

There are about 4600 waste cards covering the trenches, distributed as in Figure 24 (full data in Appendix B). In this Figure, each vertical line corresponds to a single card box. Some trenches occupy several card boxes. Up until trench 50, only a handful of cards (solely for liquid wastes) have been preserved. These may have been separated from the other cards because they were considered to be important for future reference.

As noted above, approximately 50000 items were disposed. However, the set of pink cards represents far fewer items, approximately 5000. Some types of pink cards have been retained to a greater extent than others. A higher proportion of LSB cards were retained whereas LS cards were mostly lost. The information on the pink cards for the trenches filled in the last two years of disposal operations is summarised in Sections 8.9 and 8.10.

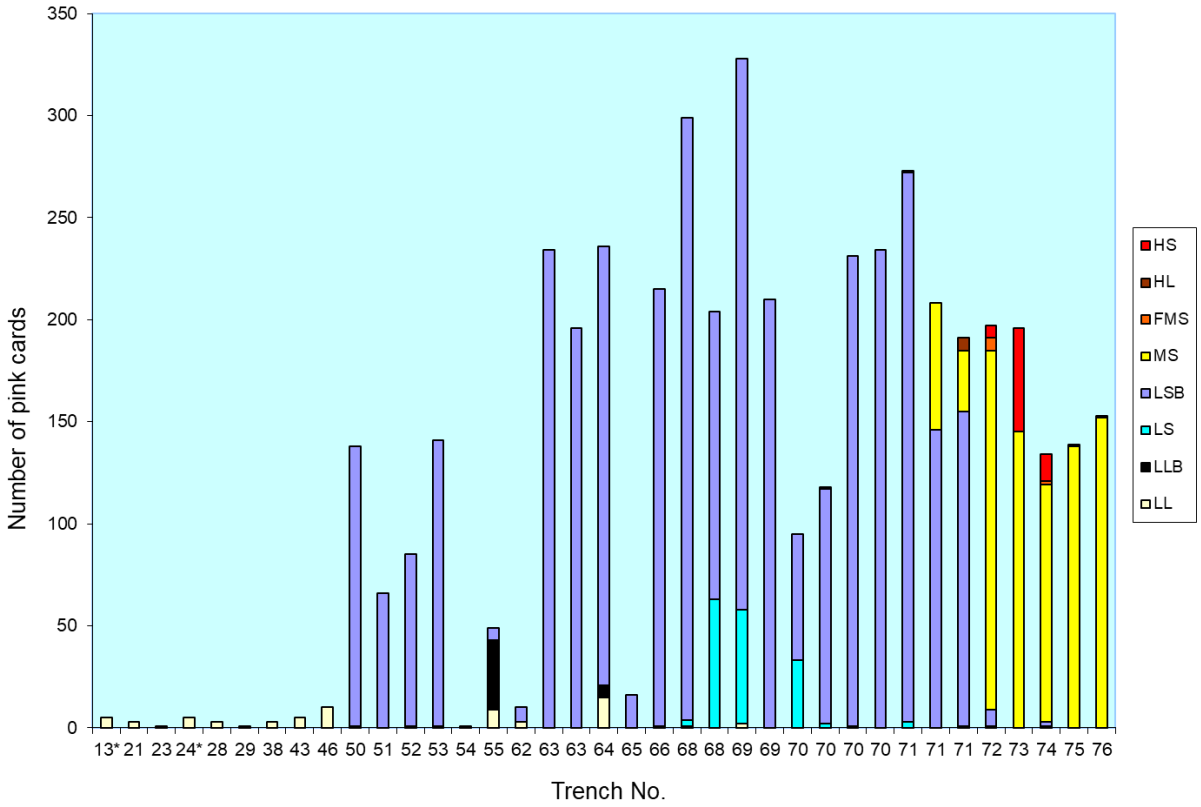


Figure 24. Distribution of pink cards retained in LFBG records (full details in Appendix B). These are counts of cards in separate boxes. In some cases multiple boxes exist for a trench (*indicates burned items).

The coverage of pink cards differs from the content of the WBBs. Although low-level liquid waste cards (LL and LLB) exist for many of the early trenches, the vast majority of the preserved cards correspond to LSB items disposed in the later trenches (Figure 24). Towards the end of disposals, the record became dominated by the newly-created category of MS (medium level solid). For trenches 72 to 76, the majority of the pink cards were in the category of MS, and there are no corresponding items in the WBB records (which had ceased).

4.3. Disposal of sludge drums

Contemporary records indicate that many steel sludge drums were buried at Little Forest. The first major disposal of sludge drums at LFBG was in Trenches 39 to 44, filled between May and October 1964. A total of 288 sludge drums were disposed in these trenches during 1964. Historic evidence strongly suggests that these disposals were intended to solve the problem of the accumulation of sludge drums at the LFBG site. This problem was extensively discussed in an AAEC report (Bonhote, 1964). One of the main issues was that the drums had been exposed to the weather following transportation to the site, and the condition of the drums had deteriorated. This meant that removing the drums from the Little Forest site was very problematic and may explain why they were eventually buried.

Following these initial disposals, the disposal of drums became sporadic, with numerous sludge drums disposed in Trenches 49, 53 and 54 (Figure 25). Significant numbers of sludge drums were disposed in many of the final trenches and the largest disposal of sludge drums was in Trench 76, the last trench filled (in late 1968).

As will be discussed in more detail below (Section 6), the sludge drums may constitute a significant part of the radionuclide inventory at the site. This contribution was overlooked for the majority of the disposal operations at LFBG. The presence of these drums and their contents may impact decisions to be made about the management of the site. The total number of drums disposed is currently estimated at 799 (in some previous documents the stated number was 760, which apparently omitted the 39 drums in Trench 73).

Some years after the cessation of disposals, it was realised that the behaviour of the radionuclides in the sludges would be a significant issue in assessing the potential for radionuclide release at the site and this topic was a subject of a detailed report (Ellis, 1977). Nevertheless, the presence of alpha-emitters was not evaluated in that report (Section 10.2).

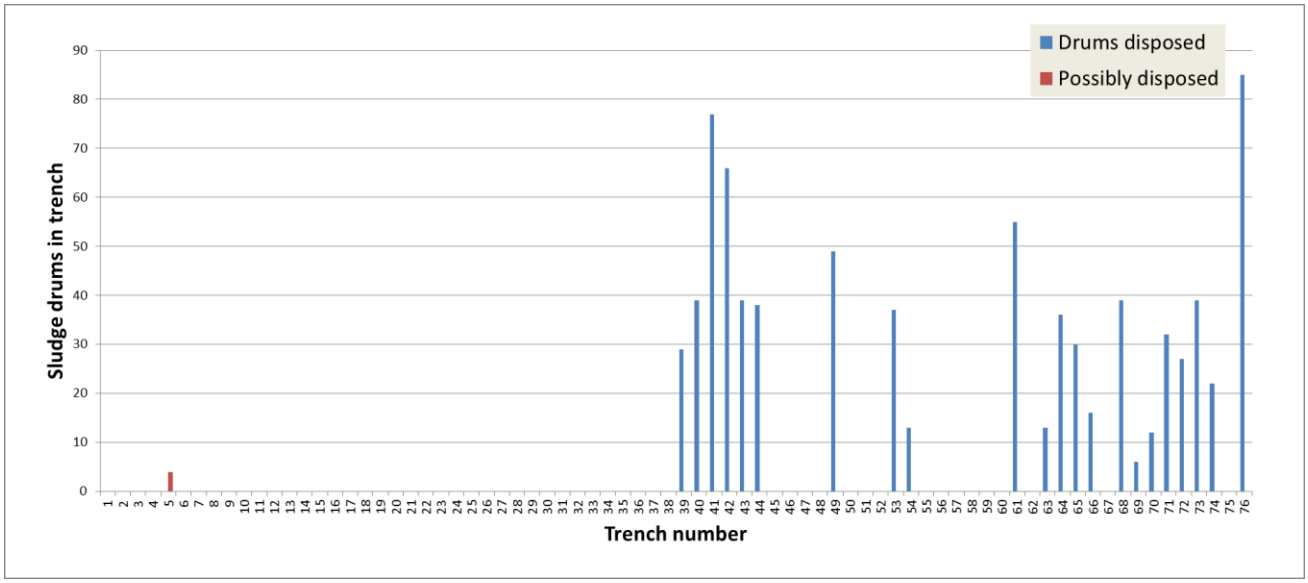
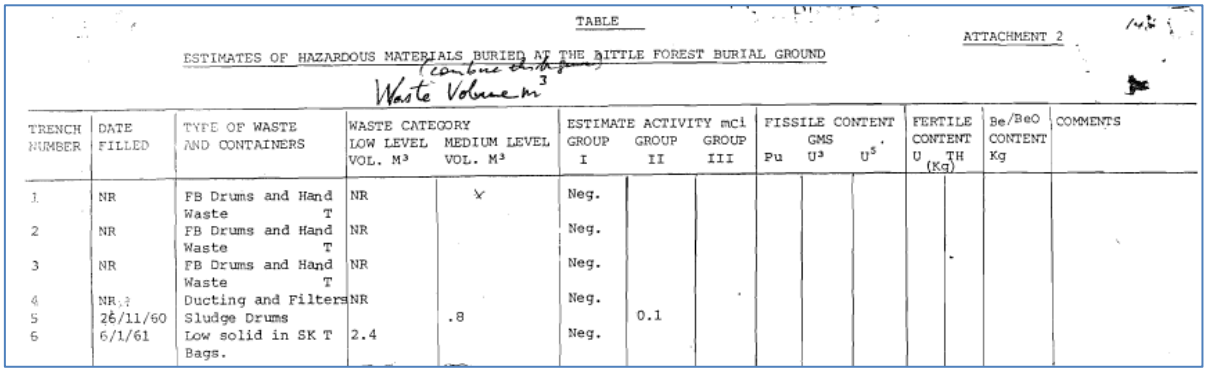


Figure 25. Number of sludge drums disposed at Little Forest by trench. The total number thought to have been disposed was 799. (Note that the 39 drums disposed in Trench 73 were omitted in previous inventories).

5. Early inventories of disposed wastes

5.1. Summary document: "Estimates of Hazardous Materials Buried at the LFBG" (EHM)

An important summary of disposed wastes is titled "Estimates of Hazardous Materials Buried at the Little Forest Burial Ground" (it appears that the information in this document was compiled in 1968, around the time of completion of disposal operations). This key source document is referred to as the "EHM" (Figure 26). It is apparently based on the Waste Burial Records (WBRs), which were also compiled in 1968 (see section 3.4). There are a few minor discrepancies between the WBRs and the EHM document, as mentioned below. An example of a WBR is given in Figure 20. The available information on the contents of each trench (taken from the EHM Tabulation) is included in Appendices D and E.



TABLE

ATTACHMENT 2

ESTIMATES OF HAZARDOUS MATERIALS BURIED AT THE LITTLE FOREST BURIAL GROUND

(combine chart form)

Waste Volume m^3

TRENCH NUMBER	DATE FILLED	TYPE OF WASTE AND CONTAINERS	WASTE CATEGORY LOW LEVEL VOL. M^3	WASTE CATEGORY MEDIUM LEVEL VOL. M^3	ESTIMATE ACTIVITY mCi GROUP I	GROUP II	GROUP III	FISSILE CONTENT GMS Pu	FISSILE CONTENT GMS U^3	FISSILE CONTENT GMS U^5	FERTILE CONTENT (Kg) U	FERTILE CONTENT (Kg) TH	Be/BeO CONTENT Kg	COMMENTS
1	NR	FB Drums and Hand Waste T	NR	X	Neg.									
2	NR	FB Drums and Hand Waste T	NR		Neg.									
3	NR	FB Drums and Hand Waste T	NR		Neg.									
4	NR	Ducting and Filters	NR		Neg.									
5	26/11/60	Sludge Drums		.8		0.1								
6	6/1/61	Low solid in SK T Bags.	2.4		Neg.									

Figure 26. The header and first few line entries in the EHM document which is one of the major records of the LFLS inventory.

5.1.1. Inconsistencies between EHM and the WBRs

The following inconsistencies between the EHM and the WBRs should be noted:

1. The EHM document exchanges the contents of Trenches 3 and 4.
2. The EHM document includes 1 mCi of Group I activity in Trench 10. This entry is not present in the WBR for trench 10 (Figure 49). This is likely to be a transcription error as Group I activity was not assigned to any trench before trench 71 in any WBR or in the EHM summary[10].

In addition, it is probable that the entries for Group I and II in Trench 75 may actually refer to Groups II and III, respectively. This would explain why the Group III activity in this trench was tabulated as zero. Typically Group III activity would be present in each trench and would exceed the Group II activity[11].

[10] Based on the SDRs, Group I activity should actually have been reported for trenches containing Pu, as documented in SDRs (i.e. #53, #55, #60, #63 #67 and others). Group I activity should also have been mentioned for all trenches containing sludges (this was only done for Trench 71 and subsequent trenches). Other Pu sources in the trenches are possible. The omission of many Pu items is not an inconsistency between the EHM and WBRs, rather it is a common feature of both documents. During the present project we have uncovered a contemporary document from 1968 which correctly allocated the Pu content of SDRs to Group I (see Figure 28) however this amount was omitted in subsequent summaries.

[11] The Waste Operations Officer who filled out this WBR form was a different person to the person who filled out the form for all preceding trenches, therefore may have been unfamiliar with the reporting system.

5.2. Comparison of the SDR and WBR records

As noted above, the main summary table upon which subsequent documents (e.g. AAEC (1985)) relied is the EHM, which incorporates the information from the WBRs. Based on the research undertaken in the present project, it has been concluded that the WBR summaries of actinides (Th-232, U_{nat} (or depleted U), U-235, U-233 and Pu) were compiled by summing the amounts reported in the SDRs which had been assigned to each trench. This comparison is shown in Table 3 below. The amounts of plutonium match exactly. The most significant discrepancy is that the SDRs appear to be inconsistent with the WBRs in terms of the distribution of some batches of U-235 between trenches 18, 19, 26 and 38. However, the combined sum of the U-235 is approximately correct. It appears that the compiler of the WBRs erroneously allocated the items in SDR 18 to trench 18 and those in SDR 19 to trench 19 [12].

The ultimate fate of a few of the items covered by SDRs is unclear. One SDR item was "presumed buried" in 1965, and another (SDR 29) has possibly been double counted. These discrepancies are probably not of any major significance. Our investigations generally agree with the waste operations officer who compiled the WBR summary (Mr P.A. Bonhote) about the interpretation of the SDR's, except for some minor confusion about a few of the U-235 items (and possibly U-233), mainly those in Trenches 38 and 47. The main possible omission is that the WBR summaries (compiled by Bonhote) assumed there were no other sources of RNs in the trenches apart from the SDRs, thereby ignoring the items accompanied by pink cards, the sludges, etc, some of which likely contained Pu. This observation leads to a major finding from the current investigation that the estimates of Pu disposed were in all likelihood underestimated to some extent, because *only* the Pu recorded on the SDRs was included in the inventory.

It can be stated that the information in the SDRs and WBRs is generally consistent. Minor discrepancies can be explained by errors in data transfer and / or by the individual packages which were covered by SDRs becoming separated. The clearest example of this is the fate of the items covered in SDR 29. These items comprised the first known burials of U-233 at LFBG and the contents of this SDR were apparently split between Trenches 47 and 48.

The comparison in Table 3 provides conclusive evidence that the SDRs were the source of information used for the fissile and fertile content of the WBRs (and in all subsequent summaries), and that no other items of activity apart from the SDR items was considered.

[12] The error probably consisted of incorrectly associating the number on these SDRs with the trench of the same number. As noted above, the WBRs were prepared relatively quickly and it is not surprising that some errors arose.

Table 3. Reconciliation of information from SDRs with the WBRs, indicating that the information is almost the same. There is a discrepancy in U-235 disposals in Trenches 18, 19 and 26 (it appears that the numbering of SDRs and WBRs was confused). The U-233 disposed in Trenches 47 and 48 is complicated by the separation of the items covered by SDR 29. There is also a discrepancy in U-235 as some SDRs were processed through the water treatment plant.

INFORMATION FROM SDRs						
Trench buried	**Th-232 (Kg)**	**U_{nat} / dep (Kg)**	**U-235 (g)**	**U-233 (g)**	**Pu (g)**	**Comparison with Waste Burial Record (WBR)**
12	0.9	0.3	0.00	0.00	0.00	Agrees
14	1.4	0	0.00	0.00	0.00	Agrees
18	0	0	0	0	0	**Discrepancy (U-235 = 5.3 g in WBR)**
19	0	0	0	0	0	**Discrepancy (U-235 = 11.63 g in WBR)**
26	0	0	28.93	0.00	0.00	**Discrepancy (U-235 = 12.0 g in WBR)**
Note: Individual trenches 18+19+26 are inconsistent between SDRs and WBR but sum of these trenches matches.						
38	0	0	4.73	0	0	Discrepancy (U-235 = 1.98 in WBR)
41	0	0	16.22	0.00	0.00	Agrees
45	0	3.8	0.00	0.00	0.00	Agrees
47	0	0	0	0	0	**Discrepancy (U-233 = 1.17 g in WBR) Fate of SDR 29 is confused.**
48	4.0	4.1	0.00	1.14	0.00	Agrees
50	0	0	8.90	0.00	0.00	Agrees
51	14.6	0.2	0	0	0	Agrees
53	0	0	0	0	1.98	Agrees
55	0	0	13.42	0.4	4.42	Agrees
58	0.02	0	4.14	0	0	Agrees
59	2.5	0	0	0	0	Agrees
60	3.3	0.32	0	0	0.02	Agrees (almost)
63	12.3	40.3	3.83	0	0.45	Agrees
67	0.06	6.8	11.13	2.50	0.01	Agrees
71	8.07	0.38	2.63	0	0	Similar but not identical
72	0	0	0.775	0	0	Agrees
74	0	2.55	0	0	0	Agrees
75	2.44	0	0	0	0	Agrees
SUM	**49.59**	**58.75**	**92.08**	**4.04**	**6.88**	Sum of the above data from SDRs
SUM	48.05	59.27	91.96	5.21	6.88	From summary in WBR/EHM of 1968.
SUM			111.72*			Includes U-235 processed through treatment plant.

Note that three SDRs containing U-235 were disposed into the waste treatment plant. These were: SDR 8 (10.8 g of U-235); SDR 10 (0.19 g of U-235); and SDR 22 (8.65 g of U-235). The U-233 in SDR 29 may have actually been split between trenches 47 and 48, but in the EHM similar amounts appear in both trenches 47 and 48 (i.e. possibly double-counted).

5.3. Estimation of beryllium disposed

A significant difficulty in estimating the amount of beryllium disposed at LFBG is that it is variously referred to as “Beryllium” and as “Be/BeO”. Given that beryllium metal is totally comprised of Be, whereas the Be content of beryllium oxide (BeO) is only about 36%, it is inevitable that there will be uncertainty about exactly how much Be was disposed at LFBG.

In the available summary tables (such as the EHM) there are individual estimates of the Be/BeO disposed in each of the trenches. These numbers seem quite precise, and it could be concluded that they were derived from some detailed information source which is no longer available. However, a closer examination of the data indicates that, in many cases, the amount of beryllium reportedly disposed is directly proportional to the number of LSB items recorded in the disposal books (Figure 27). This strongly suggests that the beryllium inventory is simply an estimate, derived from the number of LSB items. Based on the line of points in the Figure, the conversion factor seems close to 55 g of Be/BeO per LSB item. There are two implications of this finding:

- Firstly, it casts some doubt on the exact amount of Be / BeO disposed in each trench, which is presumably associated with some considerable error.
- Secondly it shows that the original WBR records, which were retrospectively generated in a relatively short period of time (but not at the time of disposals), may include rule-of-thumb estimates. These may have been used for other components other than beryllium.

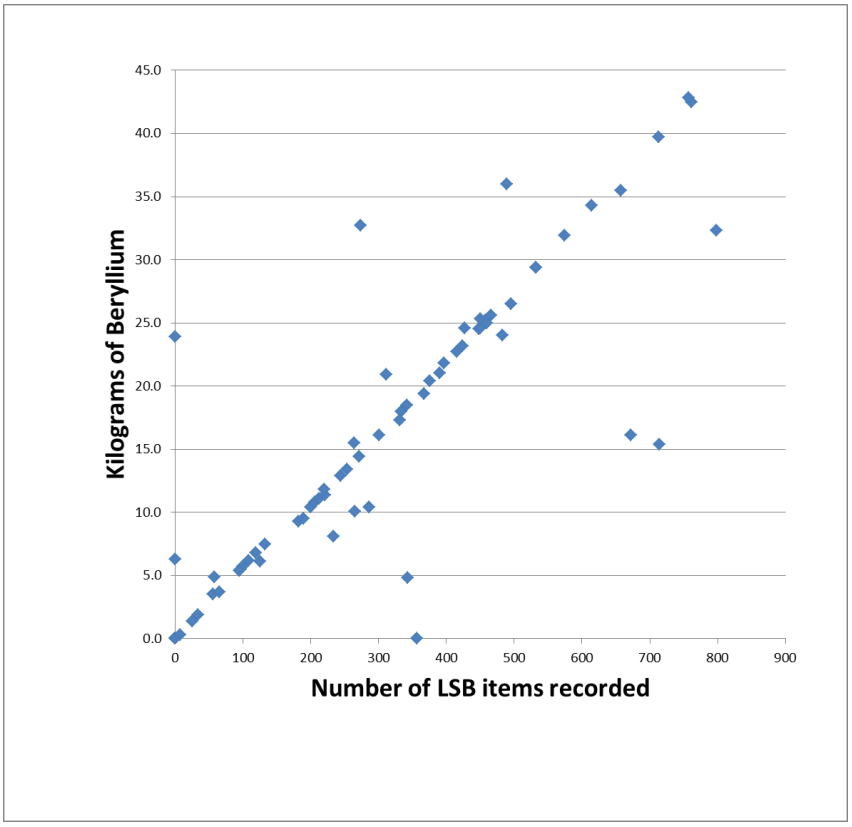
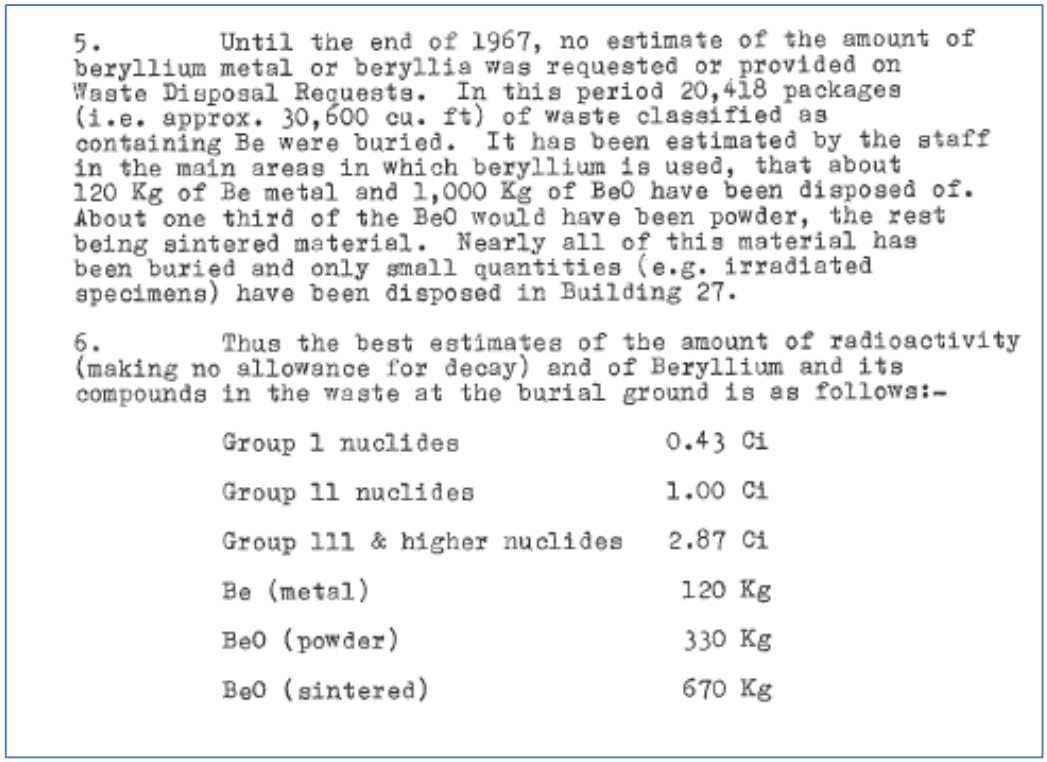


Figure 27. Relationship between number of LSB items in each trench and amount of beryllium recorded in Waste Burial Records (WBR). The linearity of many data points suggests that they may have been estimated.



5. Until the end of 1967, no estimate of the amount of beryllium metal or beryllia was requested or provided on Waste Disposal Requests. In this period 20,418 packages (i.e. approx. 30,600 cu. ft) of waste classified as containing Be were buried. It has been estimated by the staff in the main areas in which beryllium is used, that about 120 Kg of Be metal and 1,000 Kg of BeO have been disposed of. About one third of the BeO would have been powder, the rest being sintered material. Nearly all of this material has been buried and only small quantities (e.g. irradiated specimens) have been disposed in Building 27.

6. Thus the best estimates of the amount of radioactivity (making no allowance for decay) and of Beryllium and its compounds in the waste at the burial ground is as follows:-

Group 1 nuclides	0.43 Ci
Group 11 nuclides	1.00 Ci
Group 111 & higher nuclides	2.87 Ci
Be (metal)	120 Kg
BeO (powder)	330 Kg
BeO (sintered)	670 Kg

Figure 28. Extract from a document (dated 4 September 1968) which implies that the beryllium disposed in individual trenches was calculated retrospectively from a rough estimate based on the amounts of beryllium that had been used in the relevant areas before 1967. A significant proportion of the Be was in the form of powder. Note that the amount of Group I radionuclides is given as 0.43 Ci (15.9 GBq), which is similar to the amount calculated in the present report (Table 6), and apparently includes the Pu activity in the SDRs. However, a much lower Group I amount of 19.3 mCi was included in all subsequent reports before the present work (i.e. the EHM document, AAEC (1985) and Payne (2012)).

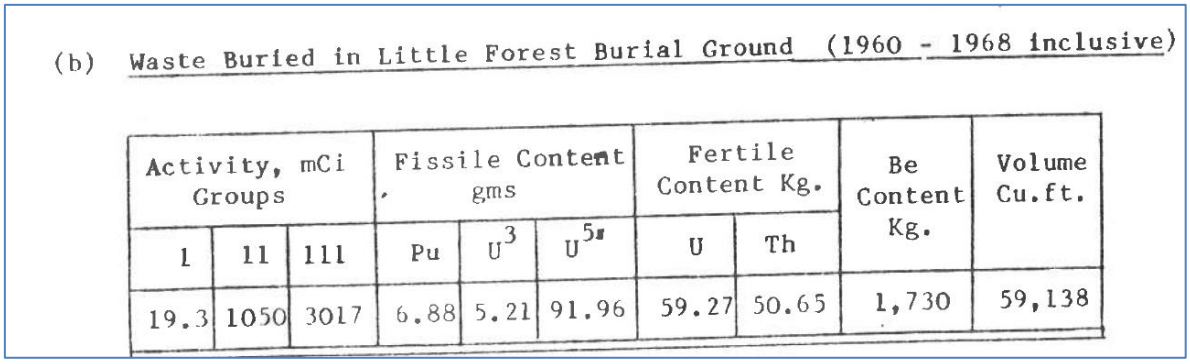
Further compelling evidence that the estimates of beryllium disposals in many trenches were calculated retrospectively comes from the historical record (shown in Figure 28) in which the number of beryllium-containing (LSB) packages disposed (before the end of 1967) as well as their volumes was mentioned, together with an estimated total amount of beryllium disposed. It would be a straightforward exercise to apportion this total between the trenches based on these figures. Dividing the total amount of Beryllium (1120 Kg) equally among 20418 packages (which were mentioned) results in an amount of 55 g per package. This is almost exactly the same as the amount inferred from the apparent linear relationship in Figure 27. Thus, it appears almost certain that the source of many of the beryllium estimates is a rule-of-thumb calculation based on the number of Be packages.

There is a significant discrepancy between the information on Be disposals given in Figure 28 and that in Figure 29. If the information in Figure 28 is accurate, then both the estimated Group I activity and the reported total Beryllium in the available summaries (such as the EHM) may be incorrect. The Group I activity is clearly significantly under-estimated in the EHM (due to the omission of the Pu activity), whereas the Be could be overestimated (mainly because most of the Be mentioned here is in the form of BeO, in which Be is only a small proportion). Conversely if the information in Figure 29 is accepted, then opposite conclusions would follow (i.e. the amounts of Group I are smaller and the disposed quantity of Be is larger). Some differences between the data in Figure 28 and that in Figure 29 can be explained by additional disposals during 1968. It seems possible, but unlikely, that the discrepancy in Be between the two summaries can be attributed to additional Be disposals in the final year of operations (1968).

5.3.1. Subsequent inconsistencies in inventory of beryllium disposed at LFBG

There have been various further discrepancies in published estimates of the total amount of beryllium disposed at LFBG. A previous summary report (AAEC, 1985) contained yearly amounts of disposed Be/BeO, which were obtained by summing the amounts in individual trenches filled in each year. A subsequent report (Payne, 2012) arrived at a total of 1070 Kg of Be / BeO disposed by adding together the individual years from the 1985 report. However, the summary of the Be disposed (given in Appendix E), which is based on the individual trench amounts in the contemporary EHM document ("Estimates of Hazardous materials buried at the Little Forest Burial Ground"), yields a total disposed of 1120 Kg. The source of this discrepancy can be traced to an error in the 1985 report, where the total Be / BeO disposed in 1963 was incorrectly given as 139.2 Kg rather than 189.2 Kg. This is likely to have been a typographical error.

Further confusion has arisen because another early report (Ellis, 1977) gave a total of 1730 Kg of Be disposed at LFBG (this was reported to be the Be content, rather than combined Be / BeO). This somewhat higher amount of disposed Be was also repeated in other reports including Cendón et al. (2015). The value cited by Ellis appears to be derived from an earlier Waste Operations report (dated December 1972, see Figure 29) where it apparently represents the total amount of Be disposed at LFBG between 1960 and 1968. It is unclear why this Waste Operations summary contains a different estimate for "Be content" (particularly given that many of the other figures for disposed wastes given in Figure 29 simply repeat those in other documents).



(b) Waste Buried in Little Forest Burial Ground (1960 - 1968 inclusive)

Activity, mCi Groups			Fissile Content gms			Fertile Content Kg.		Be Content Kg.	Volume Cu.ft.
I	II	III	Pu	U^{3}	U^{5}	U	Th		
19.3	1050	3017	6.88	5.21	91.96	59.27	50.65	1,730	59,138

Figure 29. A Waste Operations summary from 1972 which indicated 1,730 Kg as the amount of Be disposed. Although this Figure has been repeated in some later accounts (see text) it is inconsistent with the EHM record and with other documents based on the EHM.

5.4. Comments on estimation of radionuclides in categories I, II and III

5.4.1. Classification of radionuclides into groups

The existing tabulations of radionuclides disposed at LFBG (e.g. the WBRs and the EHM report) all divide the radionuclides disposed at the site into three categories (Groups I, II and III) according to an IAEA classification of the period (IAEA, 1967). The categories generally corresponded to a decreasing level of radiotoxicity, with Group I considered to be the most radiotoxic (Figure 30). Despite the use of this classification, it should not be concluded that the radionuclides were accurately known to be in these categories. Due to the vague descriptions and lack of characterisation of the waste materials, the estimates of the radionuclides in each category were necessarily approximations.

It is also important to note that the classification was based on the hazards associated with transportation of radionuclides and bulks together radionuclides which have different chemical properties, modes of decay, half-lives, and environmental behaviour. The safety of transportation is not necessarily an accurate indicator of the long-term environmental behaviour (or associated hazard) of the radionuclides.

Furthermore, the methods of calculating the inventories of these categories seem to have been rather arbitrary. A typical approach was to estimate the total activity from the measured dose-rate and then divide it between two or more of the IAEA groupings (e.g. Figure 55). As such, it could be argued that the long-established LFLS inventories, which have been based on some approximate calculations from the 1960s, can only ever be a general guide of the amount of radioactive isotopes disposed. On the other hand, it should be noted that the intervening period of a half-century will have resulted in a considerable amount of radioactive decay. In some cases, this will have significantly reduced the original inventory of particular radionuclides.

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).

Figure 30. The summary of the IAEA classifications as implemented at LFBG (Isaacs and Mears, 1977).

5.4.2. Amounts of radionuclides in Group I

According to the WBRs (and the EHM), the first trench containing Group I activity was Trench 71 (filled in early 1968). However, as discussed in more detail in Section 6, Group I activity should also have been mentioned for all earlier trenches containing sludges (this was only done for Trench 71 and subsequent trenches). Furthermore, Group I activity should have been included for all trenches containing Pu items, particularly those associated with SDRs, because several Pu isotopes are members of Group I (Figure 30). The EHM summary shows that several earlier trenches (before Trench 71) contained disposed Pu-239 / Pu-240 (based on SDR reports[13]). The omission of reported Group I activity from trenches before Trench 71 is a notable deficiency of the existing records. Even when the presence of plutonium was recorded in Scrap Disposal Reports, and this information was transferred to the WBR, it was nevertheless omitted from the Group I estimate shown on the WBR (it was only correctly included in the total Group I activity in the document shown in Figure 29, which was not used as a source of later documents). The omission of many Pu items is not an inconsistency between the EHM and WBRs, rather it is a common feature of both documents.

It is emphasised that the presence of Pu in the LFBG wastes has been acknowledged in previous reports (such as AAEC (1985)), however the total amount of Group I radionuclides has been significantly under-estimated. Based on the SDRs, Group I activity should actually have been reported for all trenches containing Pu, as documented in SDRs (e.g. Trenches 53, 55, 60, 63 and 67, see Table 3). During the present project, we have uncovered a contemporary document from 1968 which apparently allocated the Pu content of SDRs to Group I (see Figure 28) however this amount was omitted in subsequent summaries.

It should also be noted that any plutonium reported on pink cards was not accounted for as contributing to Group I (unless associated with an SDR). The reason that Trench 71 was included as contributing to Group I was that, for the first time, the sludges were recognised as containing Group I activity when this trench was filled. This can be seen by comparing waste cards for sludge drums disposed in trench 70 and 71 (as discussed further below, also see Figure 32). By this time, more than 500 sludge drums had already been disposed. Thus, it can be concluded that the Group I content was omitted for the majority of the 799 sludge drums disposed at the site, together with the Group I content of the SDRs.

5.4.3. Radionuclides in Groups II to IV

As has been discussed, rough rules of thumb, based on external dose-rates, were used to allocate radionuclides to groups II and III. Furthermore, although numerous pink cards mentioned high levels of tritium (Group IV), the presence of tritium in the waste seems to have been largely ignored when the summaries were prepared. It should be noted that tritium is considered to be a less hazardous radionuclide (hence categorised as Group IV), but nevertheless its omission from the disposal records subsequently caused some confusion. For example, a later summary report in the 1980s (AAEC, 1985) stated that the origin of the tritium plume at the site (which by then had been detected) was hard to explain, due to the apparent absence of recorded tritium sources (see Sections 5.5 and 8.5.3).

5.4.4. Inclusion of SDR radionuclides from Groups I, II and III

Given that the radionuclides described on the SDRs were omitted from the published total activity estimates of Groups I-III radionuclides, we have assessed whether the inventories of Group I, II and Group III radionuclides were significantly impacted by the information in the SDRs. This work consisted of two parts. Firstly, the radionuclides on the SDRs were compiled, and secondly, estimates for the conversion of the masses of these radionuclides to activities were derived (Table 4).

For most of the radionuclides this is a trivial exercise, as the specific activity is simply related to the half-life and is accurately known (e.g. U-233 and U-235). For U_{nat} and Th_{nat} certain assumptions need to be made about the state of equilibrium in the decay chain of the radionuclides (and whether progeny radionuclides have been removed). However, these assumptions are of little consequence because U_{nat} and Th_{nat} turned out to be relatively minor contributors to Group III[14].

[13] It is likely that the disposed Pu also contained significant activities of Pu-241 (another Group 1 radionuclide). This cannot be directly deduced from the disposal records, but can be inferred from the widespread detections of Am-241 in environmental samples (and from the likely isotopic composition of typical Pu samples).

[14] This does not necessarily mean they make no contribution to the dose calculations for the site.

Plutonium is the most complicated case, because the conversion from mass of plutonium to specific activity depends on the ratio of the different Pu isotopes. As shown in Table 4, isotopically pure Pu-240 and Pu-239 have different specific activities (8.35 GBq/g and 2.31 GBq/g respectively). The isotopic mix of Pu-239 / Pu-240 used for the calculations was based on environmental measurements at Little Forest undertaken during the current project, which indicated approximately 92.6% Pu-239 (by mass)[15]. As such, the specific activity of Pu disposed is estimated as 2.79 GBq/g, which is a weighted average of the activities of Pu-239 and Pu-240 present. Note that by alpha-activity, the split between Pu-239 and Pu-240 is 76% Pu-239 and 24% Pu-240.

In these calculations, only the alpha-emitting Pu isotopes (Pu-239 and Pu-240) were considered as contributing to Group I. The short-lived isotope, Pu-241, is a beta-emitter, and is also categorised as a member of Group I (Figure 30). While a significant activity of Pu-241 may have been disposed at LFBG, very little Pu-241 activity now remains (several decades after disposal) due to the short half-life of Pu-241 (~14 years).[16]

The Group I activity for each of Trenches 53, 55, 60 63 and 67 was estimated based on the information in the SDRs (which mostly matches the information in the WBRs, as discussed above). This enabled the activity (GBq) of Pu in each of these trenches to be estimated (Table 5). Similarly, the activities of U-233, U-235, U_{nat} and Th_{nat} in each individual trench were calculated and the contributions to their respective activity groups were determined.

Table 4. Summary table of specific activities of radionuclides mentioned on SDRs. Note that the specific activities of U_{nat} and Th_{nat} include progeny (i.e. exceed the activity of pure U-238 and Th-232).

Gp	Isotope	Bq/g	**GBq/g**
I	Pu-240	8.35 E+09	8.35
I	Pu-239	2.31 E+09	2.31
I	Pu-239 (92.6%) + Pu-240 (7.4%)	2.79 E+09	2.79
II	U-233	3.59 E+08	0.359
III	U-235	7.93 E+04	0.0000793
			GBq/Kg
III	U_{nat}	1.79 E+05	0.179
III	Th_{nat}	4.04 E+04	0.0404

[15] This is consistent with a Pu-239/Pu-240 mass ratio of 0.08.

[16] There is some residual Am-241 activity at the LFLS derived from decay of Pu-241.

Table 5. Previously omitted amounts of Group I activity (Plutonium), Group II activity (U-233) and Group III activity (based on information in the SDRs). The inclusion of Pu in the Group I inventory increases the Group I inventory at LFLS (previously < 1 GBq) by a factor of more than 20. The inventory of Group II and Group III radionuclides is not significantly increased by the inclusion of the radionuclides recorded in the SDRs.

TRENCH	Grams Mass **Pu(239+240)**	GBq Activity (Group I)
53	1.98	5.5
55	4.42	12.2
60	0.02	0.1
63	0.45	1.3
67	0.01	0.0
	Total	19.1

TRENCH	Grams Mass **U-233**	GBq Activity (Group II)
47	1.17	0.42
48	1.14	0.41
55	0.40	0.14
67	2.50	0.90
	Total	1.87

TRENCH	Grams Mass **U-235**	GBq Activity (Group III)
18	5.30	0.00042
19	11.63	0.00092
26	12.00	0.00095
38	1.98	0.00016
41	16.22	0.00129
50	8.90	0.00071
55	13.42	0.00106
58	4.14	0.00033
63	3.83	0.00030
67	11.13	0.00088
71	2.63	0.00021
72	0.78	0.00006
	Total	0.00729

TRENCH	Kg Mass **U_{nat}***	GBq Activity (Group III)
12	0.3	0.054
45	3.8	0.680
48	4.1	0.734
51	0.2	0.036
60	0.3	0.057
63	40.3	7.214
67	6.8	1.217
71	0.9	0.154
74	2.6	0.456
75	0.0	0.007
	Total	10.609*

TRENCH	Kg Mass **Th-232***	GBq Activity (Group III)
12	0.9	0.036
14	1.4	0.057
48	4.0	0.162
51	14.6	0.590
58	0.02	0.001
59	2.5	0.101
60	3.1	0.125
63	12.3	0.497
67	0.06	0.002
68	1	0.040
71	5.73	0.231
73	1.723	0.070
74	0.4	0.016
75	0.06	0.002
76	0.55	0.022
	Total	1.953*

*Includes progeny (i.e. members of decay chains).

5.4.5. Effect of Pu from SDRs on inventory of Group I radionuclides

The Figures in Table 5 can be used to estimate the impact of the items in the SDRs on the inventory of radionuclides in Groups I to III. These can be compared to previous disposal summaries. According to the contemporary EHM summary in Appendix E, a total of 19.3 mCi (millicuries) of Group I activity was disposed during the operational period of LFBG. This estimate (which corresponds to approximately 0.7 GBq) failed to include some major sources of Group I activity, such as the Pu items reported on the SDRs. This Pu amounts to approximately 19.1 GBq (Table 5). Thus, the inclusion of Pu from SDRs increases the Group I inventory at LFLS by a factor of more than 20 (Table 6). The other Radionuclide Groups (i.e. Groups II and III) are not significantly impacted by the inclusion of the activities from the SDRs, in both cases accounting for approximately 5-10% of additional activity in these Groups.

As mentioned above, there is one operational record (from 1968) which provides a similar estimate of the Group I inventory to the one we propose in the present report. An extract from this record is shown in Figure 28. It shows a Group I inventory of 0.43 mCi. This was approximately 20 times higher than the Group I inventory reported in the EHM which was later placed on the public record (AAEC, 1985). While the 1985 report acknowledged the disposals of plutonium at the site, it failed to include the activity of this Pu in the Group I inventory.

It should be noted that the sludge drums also affect the inventory of Group I activity. This source of Group I activity was omitted for the vast majority of drums disposed at LFLS. However, it will be shown (in Section 6.2) that the total activity of Group I derived from the sludge drums was probably much less than the Pu activity which can be derived from the SDR information.

Table 6. Activity contributed by SDR items in Radionuclide Groups I to III

Radionuclide Group	**Previously reported activity (GBq)[a]**	**Activity in SDRs (GBq) (**Table 5**)**
I	0.75	19.1
II	39.10	1.9
III	111.50	12.6

[a] Reported in previous summaries (AAEC, 1985; Payne, 2012)

5.5. Were all radionuclide disposals accounted for?

A key issue in assessing the LFLS records is whether the radionuclides reported in the inventory included all possible sources of activity or whether some items were overlooked. As discussed above, the inventories of important radionuclides such as plutonium (Pu-239, Pu-240) and U-233 were compiled entirely from the information on a very small number of scrap disposal reports (7 SDRs in the case of Pu).

While only the SDR items were considered when compiling the reported inventory of several key radionuclides, it is likely that other items contaminated with the same radionuclides were disposed at LFBG. For example, glove box cleanings were disposed in numerous trenches (as verified by pink cards) and additional similar items could be among the 45,000 items for which the pink cards are missing. This could increase the inventory of Pu by an unknown amount. One possible way to approach this question is to consider the laboratories giving rise to the waste as reported in the WBBs (see Section 7.4). It is possible that some items from these laboratories would be contaminated with Pu (similar to the items listed on SDRs), or other amounts of Pu were in the wastes – from spills, clean ups and unquantified waste disposals. These questions will be considered in a subsequent report (E-789), where an attempt is made to put upper and lower bounds on the amounts of radionuclides disposed.

Although tritium was never tabulated in any inventory, there is abundant evidence that tritium was disposed at LFLS. This evidence includes the pink cards, the detected plume of tritium, and the documented operations of the HIFAR reactor. While it is difficult to provide a precise estimate of tritium disposed, the extent and concentrations of tritium in the plume provide some indication of the inventory.

The situation with Pu-241 and Am-241 is similar to tritium. Although the disposal of Pu-241 (or Am-241) was rarely reported at LFLS during the years of operation, these isotopes were probably present in all the samples which were contaminated with plutonium, and further Am-241 will have been derived from decay of Pu-241 in the years since disposal.

Similar difficulties in inventory estimation exist for many other radionuclides. Given that around 50,000 items were disposed, many of which were described in very vague terms, additional unknown quantities of any isotopes associated with the Lucas Heights facility may have been disposed during the operations at the LFBG.

5.6. Sources of uncertainty in inventory

Based on the information surveyed in this report, there are several possible reasons which imply that the previously published radionuclide inventory may be inaccurate. One of the reasons is simply the inherent difficulty of estimating the exact contents of every container which may have entered the waste stream. This estimate was largely based on the comments of the person seeking to dispose the waste, and in some cases an external dose rate. Furthermore, many waste packages contained isotopes categorised as “Mixed Fission Products” (MFP), a rather imprecise description which probably reveals some lack of knowledge about the specific waste. This terminology was also used at waste sites overseas, creating similar issues elsewhere. The contemporary records indicated that the operators could not accurately estimate the amounts of isotopes present, a factor which was a specific consideration when an increase in permissible disposal activities was being considered (see Section 7.1, particularly Figure ***37***).

The main identified sources of uncertainty are considered to be the following:

- Failure to consider possible disposals of Pu, U-233, and other actinides, in addition to those itemised on the limited number of SDRs. These isotopes were mentioned on numerous pink-cards (e.g. Section 8.6.3 and following sections), but only the information in the SDRs was used in compiling the inventory.
- Overlooking the radionuclide content (particularly alpha-emitters) of sludges for the majority of the steel drums disposed before 1968 (the final year of operations). This matter is considered further in the following chapter.
- The radionuclide content (both identity and amount) of some disposed items was not estimated or recorded (e.g. 3 glove boxes in Trench 51, see Section 8.6.4).
- Omission of tritium (Group IV). Tritium was considered to be a relatively minor hazard, but nevertheless the implications of its presence and mobility were generally not evaluated in contemporary accounts. Furthermore, its origin was mistakenly attributed to an “external organisation such as a university or state government department” in the public report of 1985 (AAEC, 1985).
- Omission of Pu-241. At the time of disposals, and in the early years since disposal, this radionuclide probably constituted a significant source of activity[17].

While underestimates of the inventory are likely for various reasons, there is the possibility that in some cases inventories were over-estimated, as proposed in AAEC (1985). For example, using the surface dose rates to estimate the amount of Group II and III in packages may have resulted in an over-estimate of the radionuclide activity. This may also apply to the total amount of beryllium, where it is possible that not every waste package labelled as beryllium-contaminated (i.e. LSB) actually contained a significant amount of beryllium. As noted above (Section 5.3), there is strong evidence that the amount of beryllium disposed per trench was retrospectively calculated, based on the total amount of beryllium which was unaccounted for following beryllium operations at the Lucas Heights site. It is possible that the missing beryllium could be partly accounted for in some other way.

[17] The relatively short half-lives of isotopes such as tritium and Pu-241 mean that the present-day activity of these radionuclides will be significantly lower than at the time of waste disposals in the 1960s.

6. Radionuclide content of the sludge drums

6.1. Sludge drums in the LFBG disposal records

As has been noted above, the sludge drums are an important part of the LFLS radionuclide inventory. The activities of Group II and Group III radionuclides were estimated for all drums disposed at LFBG and included in contemporary summaries (such as the EHM). However, the Group I activity in the sludge drums was only considered for Trench 71 and subsequent trenches (see comparison of pink cards for Trenches 70 and 73 in Figure 32). In other words, the Group I content of only 205 (or possibly 166) of the 799 disposed sludge drums was included in the inventory[18].

In the first few years of operations of LFBG, no drums were buried, but many of them were moved to the LFBG and stored on the ground surface. This created major difficulties, because they were corroding and by this time it was considered "doubtful" that they would withstand transport back to the main Lucas Heights site. This situation was documented in a report in 1964 (Bonhote, 1964). Approximately 12,000 gallons of sludge (272 drums) were stored at the LFBG site at this time. Thirteen empty drums were buried in Trench 38 in March 1964. It is not clear what happened to the contents of these drums. Subsequently 288 drums of sludge were buried in trenches 39 to 44 during the next few months of 1964. As shown above (Figure 25), disposals of sludges occurred in many trenches. However, the radionuclide content of these was accounted inconsistently. Furthermore, the contents of individual sludge drums were estimated, rather than measured, in many cases.

The 1964 document about the sludge drums suggested the activity levels depicted in Figure 31.

α activity	: 10^{-6}	to 10^{-4} μc/ml
β activity	: 10^{-4}	to 10^{-2} μc/ml
Beryllium	: 20	to 50 p.p.m.

Figure 31. Activity of sludges proposed by Bonhote (1964)

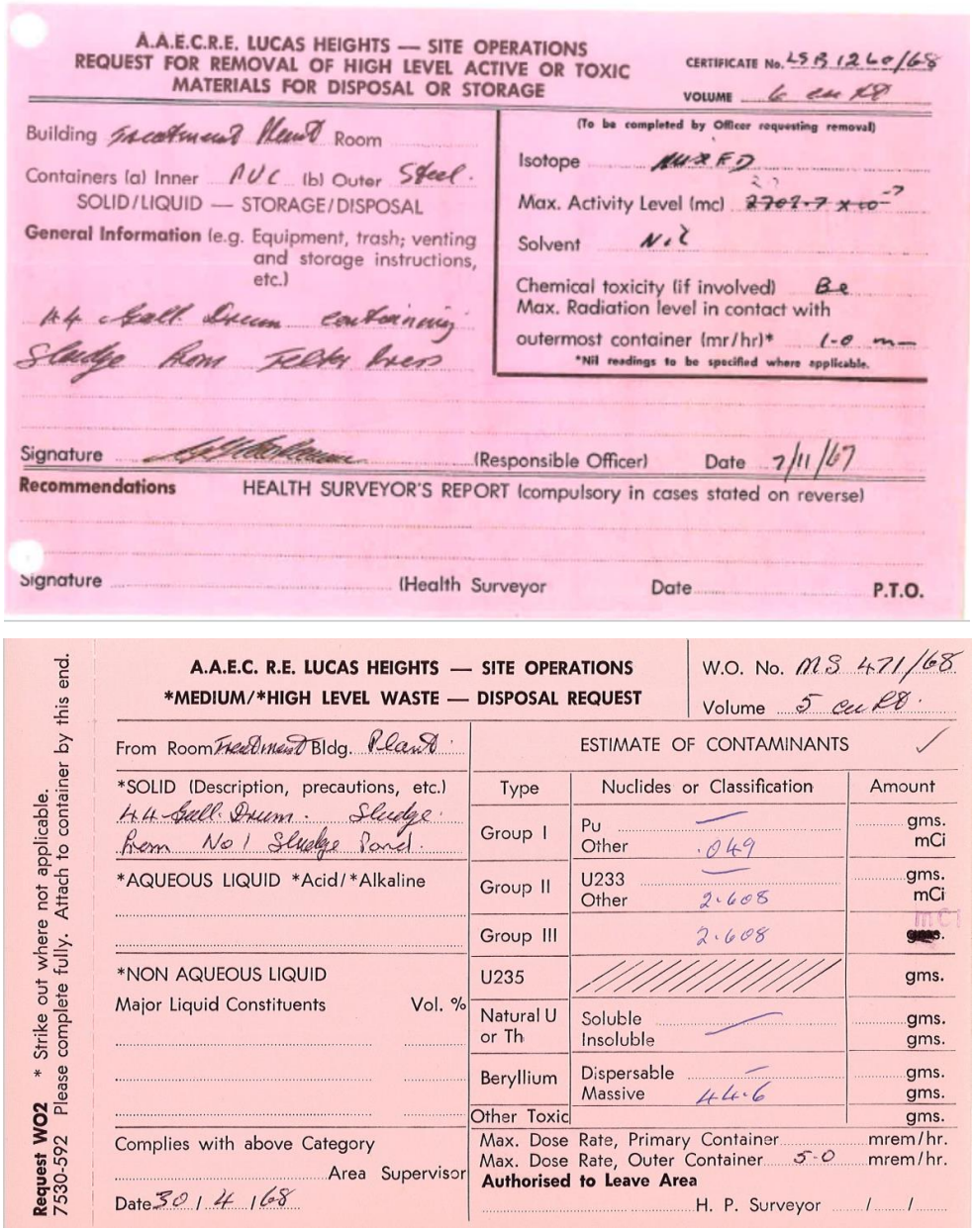
For each 200 L drum, these ranges correspond to:

- Alpha – 0.2 μCi to 20 μCi / 200 L (i.e. 0.02 mCi).
- Beta – 20 μCi to 2 mCi / drum.

For the first drum disposals in Trench 39, the total activity was estimated as 0.5 mCi per drum. Hence the 29 drums disposed added up to 14.5 mCi. This was assumed to be evenly split between Group II and Group III. This explains the reported activity in Trench 39 (Appendix E, see also Section 8.5.1). The estimate of 0.5 mCi activity per drum (assumed to be evenly split between Groups II and III) continued until at least Trench 54.

Trench 71 was the first trench for which disposal of Group I activity was recorded (using the type of card shown in the lower panel of Figure 32). The summary information for the wastes is tabulated in Appendix E (where Group I activity has been reported in Trench 71 but not for Trench 70). The change in accounting method can be seen by comparing the items shown in Figure 32, which are both "Steel drums containing sludge from a filter press". Although both items were generated during the 1968 financial year, they were categorised in different ways. It seems improbable that the content of the waste stream suddenly changed. Note that, as per previous practice, the Group II and Group III contents were equal. This reflects the estimation methods and assumptions which were made in reporting the radioactivity present in the sludges.

[18] This number is in itself uncertain, because it is not known whether the estimated radioactivity contents of the 39 drums in Trench 73 were included in the previous inventory. In this discussion, we will assume that all 205 drums were taken into account.



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. 458 1260/68
VOLUME 6 cu ft

Building Treatment Plant Room
Containers (a) Inner PVC (b) Outer Steel.
SOLID/LIQUID — STORAGE/DISPOSAL
General Information (e.g. Equipment, trash; venting and storage instructions, etc.)
44 Gall Drum containing Sludge from Filter Bed

(To be completed by Officer requesting removal)
Isotope MIXED
Max. Activity Level (mc) 2702·7 x 10⁻⁷
Solvent Nil
Chemical toxicity (if involved) Be
Max. Radiation level in contact with outermost container (mr/hr)* 1·0 m—
*Nil readings to be specified where applicable.

Signature ..... (Responsible Officer) Date 7/11/67
Recommendations HEALTH SURVEYOR'S REPORT (compulsory in cases stated on reverse)
Signature ..... (Health Surveyor Date ..... P.T.O.

Request WO2 7530-592 * Strike out where not applicable. Please complete fully. Attach to container by this end.

A.A.E.C. R.E. LUCAS HEIGHTS — SITE OPERATIONS
*MEDIUM/*HIGH LEVEL WASTE — DISPOSAL REQUEST

W.O. No. MS 471/68
Volume 5 cu ft

From Room Treatment Bldg. Plant
*SOLID (Description, precautions, etc.) 44 Gall. Drum. Sludge. Rem No 1 Sludge Bed.
*AQUEOUS LIQUID *Acid/*Alkaline
*NON AQUEOUS LIQUID
Major Liquid Constituents Vol. %
Complies with above Category
Area Supervisor
Date 30/4/68

ESTIMATE OF CONTAMINANTS ✓

Type	Nuclides or Classification	Amount
Group I	Pu	gms.
	Other ·049	mCi
Group II	U233	gms.
	Other 2·608	mCi
Group III	2·608	gms.
U235		gms.
Natural U or Th	Soluble	gms.
	Insoluble	gms.
Beryllium	Dispersable	gms.
	Massive 44·6	gms.
Other Toxic		gms.

Max. Dose Rate, Primary Container ..... mrem/hr.
Max. Dose Rate, Outer Container 5·0 mrem/hr.
Authorised to Leave Area
..... H. P. Surveyor ...../...../.....

Figure 32. Comparison of a sludge drum waste card for Trench 70 (top) and Trench 73 (below). The change of recording Group I activity after Trench 70 is part of a line of reasoning which suggests that many preceding trenches contained unreported Group I activity.

Therefore the RN inventory of nearly 80% of the sludge drums (over 500 drums) was ignored in the EHM compilation (there is also some uncertainty about whether the 39 drums disposed in Trench 73 were taken into account[19]). The omission of a substantial number of sludge drums is one of the major potential sources of uncertainty in the reported inventory estimates. Possible approaches to this problem are considered in the following section.

[19] Based on the inclusion of Group I activity for this trench in the inventory it appears probable that the activity was accounted for in the EHM document (Appendix E) although the number of sludge drums was omitted.

6.2. Group I activity of sludge drums in final trenches

One way to approach this important issue (i.e. to estimate the Group I sludge activity disposed in the trenches prior to Trench 71) is to consider the amounts of Group I activity within the sludges disposed in the small number of trenches for which we have detailed data (as reported on pink cards). These are trenches 71, 72, 73, 74 and 76. For these trenches, estimates of Group I activity exist in the EHM summary record, which are almost certainly due to the inclusion of activity estimates for the sludge drums. As such, we can attempt to utilise the activity reported on the individual pink cards for the drums placed in these trenches. The distribution of reported Group I activities in drums in these trenches is summarised in Figure 33 and Figure 34.

It is immediately apparent that the sludge drums were highly variable in their individual Group I activities, ranging from 0.01 mCi for a number of drums, up to 0.65 mCi for the two highest activity drums disposed in Trench 76. Note that the most active of these drums considerably exceeded the average Group I activity of the 205 drums for which pink cards exist (0.042 mCi / drum). The average activity of drums in this trench was also unusually high (approximately 0.07 mCi/drum). This variability may be attributed to possible processing differences or the impact of occasional spills in active laboratories.

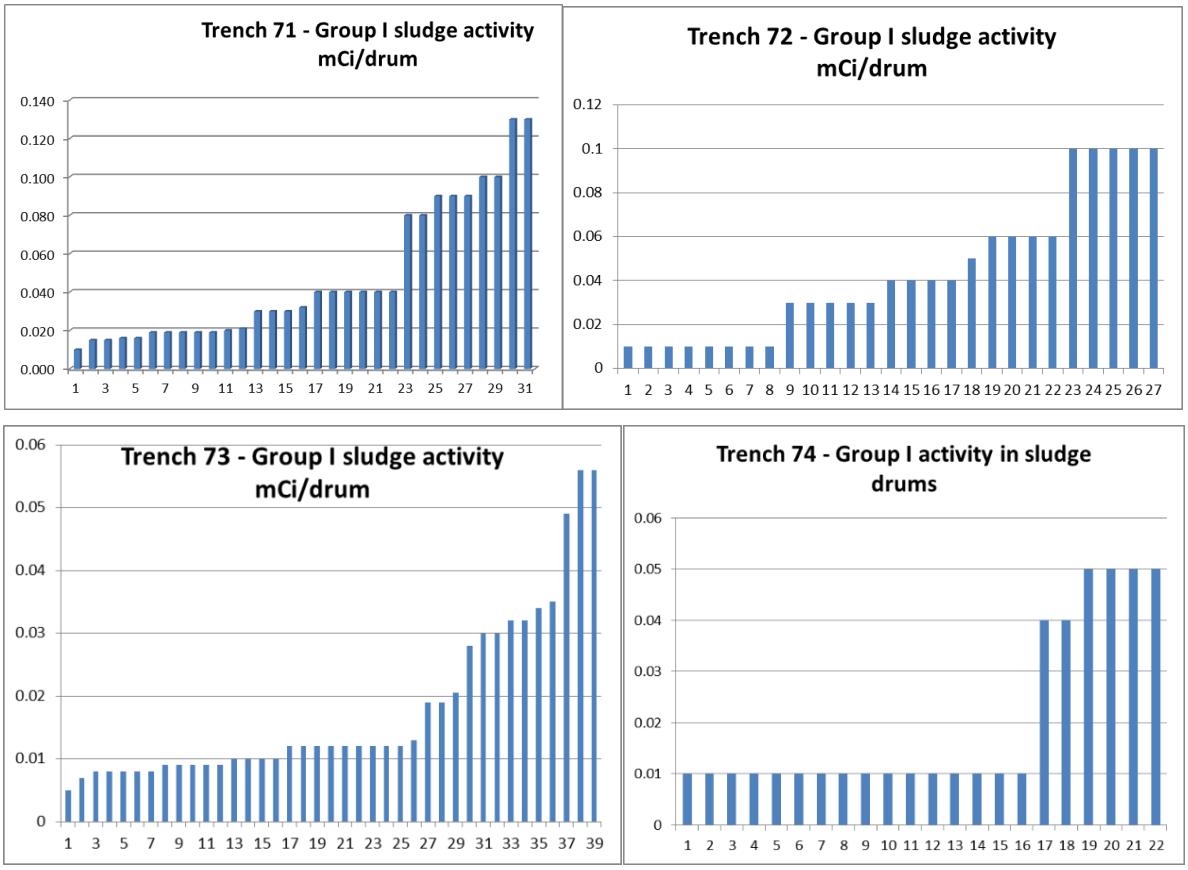


Figure 33. Distribution of Group I activity in Trench 71 to 74. Note that the horizontal axis shows the number of individual drums in each trench (see also Appendix D and Figure 25).

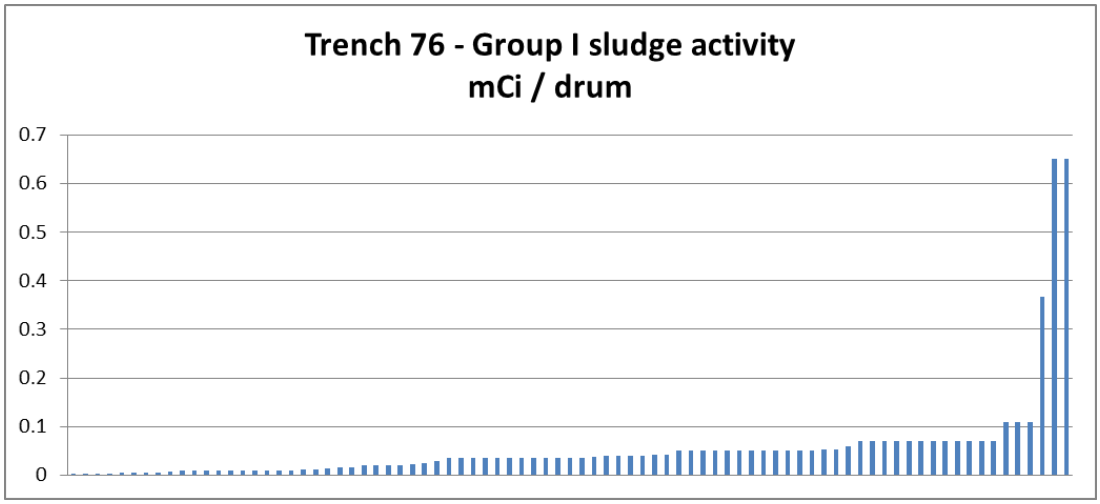


Figure 34. Distribution of activity of the sludge drums in Trench 76. Most drums contained less than about 0.1 mCi of Group I activity. Three drums had much higher activities, possibly because of processing differences or the impact of occasional spills in active laboratories.

The data from the pink cards can be used in various ways to attempt to derive an "average" sludge drum activity, which should provide an improved estimate of the Group I contribution of the entire set of sludge drums. For example, consider the total number of 205 sludge drums in these 5 trenches. The total of the individual activities on the available pink cards for these drums (Table 7) yields a combined Group I activity of 8.5 mCi. This corresponds to an average Group I activity of 0.042 mCi per drum (this Figure would be slightly different if the 39 drums in Trench 73 are excluded). It is possible to extrapolate from this average and assume that the total Group I activity in the 799 sludge drums disposed would be around 33.6 mCi (approximately 1.3 GBq) if every drum was allocated 0.042 mCi (this assumes that the known drums are representative of the entire set). This calculation would therefore increase the Group I inventory from the sludge drums from 0.75 GBq to 1.3 GBq. Although substantial, this is a relatively small increase compared to the Group I activity from the SDRs shown in Table 6.

The average Group I activity derived here is significantly higher than what would be estimated from the 1964 estimates of alpha activity in the sludge drums (i.e. a maximum of 0.02 mCi/drum) (Bonhote, 1964). The Group I was typically assumed to be a third of the total alpha, hence the Group I activity for each drum would be below 0.01 mCi (based on the 1964 estimate). Thus, either the activity of the drums measured in 1964 was under-estimated, or the amount of activity in the sludge drums increased between 1964 and 1968.

As indicated in the caption to Figure 34, an even higher estimate for the Group I activity of these 594 earlier drums could be arrived at if the average for Group I activity for Trench 76 (0.074 mCi) applied for the 594 missing drums, approximately an extra 42 mCi or 1.56 GBq of Group I activity (total of 2.3 GBq Group I activity in the sludges). This is clearly a conservative (over) estimate, but is nevertheless much smaller than the Group I activity from the SDR plutonium content (Table 6).

An extrapolated estimate of activities in the unknown sludge drums is presented in Figure 35. The aim of this figure is to illustrate the possible Group I activity for sludge drums in trenches prior to Trench 71. As can be seen from the purple line (open circles), these were given a zero Group I activity content in the previous reports (such as the EHM). However, non-zero values can be derived based on the average data for Trenches 71, 72, 73, 74 and 76. The red-line extrapolates the average activity (0.042 mCi/drum) for known drums (Trenches 71-74 and 76) across all the unknown drums. This indicates that Group I activity probably should have been estimated for trenches prior to Trench 71. For trenches 71 and 76, the reported activity (purple) is actually higher than would be calculated based on this average (red), with the converse being true for Trenches 73 and 74.

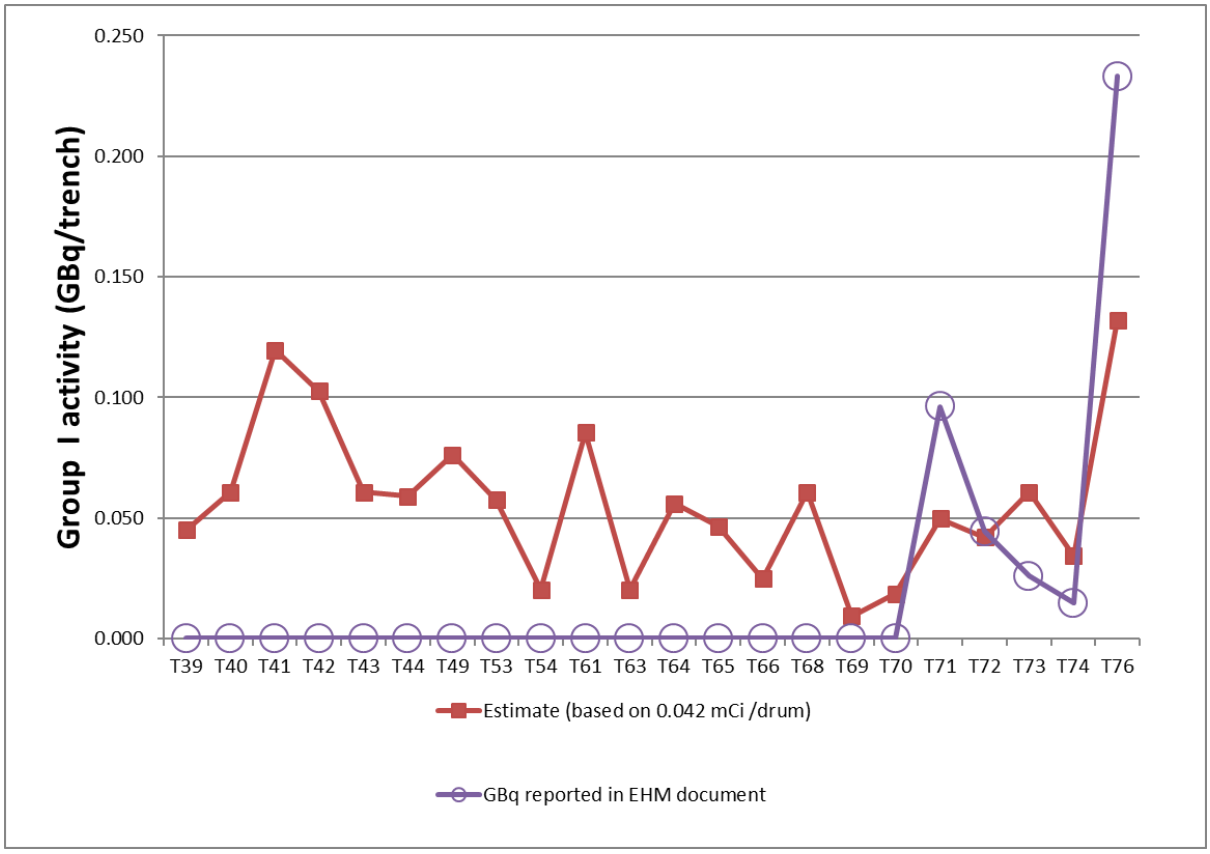


Figure 35. Possible estimates for the Group I activity from the sludge drums based on reported (purple) and estimated (red) sludge compositions. Note that the Group I Activity reported in existing documents (derived from the EHM) is zero for all trenches up to Trench 70 (open circles).

Because the Group I activity of so many drums was previously omitted (despite the acknowledged presence of sludge alpha activity in the report of 1964), it is inevitable that the Group I inventory at LFBG must be substantially increased due to the presence of the sludges. While we have attempted to do this (above) by analysis of each individual pink card, a simpler estimate is simply to increase the inventory by a factor of a factor of around 4. This acknowledges that only around 200 of the ~800 disposed drums were previously included in the inventory. By this simple estimation, the amount of Group I radionuclides in the sludges would be increased from around 0.75 GBq to 3 GBq.

It is worth commenting on the slight discrepancies in the different estimates for total Group I activity in the sludges, which range from approximately 1.3 GBq to 3 GBq. While these are all greater than the known inventory of approximately 0.75 GBq of Group I in the sludges, the exact figure depends on assumptions about:

- How representative the drums for which we have data are of the entire set of drums
- How the apparent typographical error in the previous estimate (EHM) of Group I activity in Trench 75 should be re-interpreted (this amount contributes over 40% of the stated Group I activity at LFLS).
- How the previously “missing” 39 drums in Trench 73 are accounted for.

Regardless of the method of calculation, it is clear that neglecting the amount of Group I activity in the sludges until the final few trenches filled resulted in a significant under-estimate of the total Group I activity disposed. This omission may have been realised during the course of the disposals during 1968, and may have been a contributing factor to the cessation of disposals at the site.

6.3. Further comments on sludge drums and inventory calculations

The reported information on Trenches 71 to 76 can be used to cross-check several aspects of the previous summaries and attempt to verify the previously-reported data (see Table 7). In this table, the previous data (EHM) for the inventory of these trenches is shown in the yellow columns, and the data obtained from going through the existing pink card sets in the pink columns (these are separated between the activities known to be sludges and the total activities from the pink cards). For these trenches, there is no other way of verifying the EHM information as no burial books (WBBs) exist.

Table 7. Cross-tabulation of various information relating to trenches 71 to 76.

		ESTIMATED ACTIVITY mCi (Previous - EHM)				Sludge activity from Pink Cards (mCi).			Total activity from Pink Cards (mCi)[b]		
		GROUP				GROUP			GROUP		
Trench	Number of drums	I	II	III	Number of drums	I	II	III	I	II	III
71	32	2.6	302	1150	32	1.5	49	49	1.7	302	142
72	27	1.2	137	667	27	1.2	31	31	4.7	46	82
73	(0)	0.7	38	238	39	0.7	24	24	0.7	31	69
74	22	0.4	28	221	22	0.4	23	23	0.4	34	1233
75	0	8.1[a]	40	0	0	0.0	0	0	0.0	12	80
76	85	6.3	58	171	85	4.7	49	49	4.7	59	156
TOTAL	166	19.3	570	2488	205	8.5	175	175	12.2	484	1762

[a] It is noted that there is an apparent transcription error in the EHM inventory of Trench 75. It appears that this error had allocated Group II to Group I; and Group III to Group II. (See Appendix E).

[b] For this group of Trenches, the activity of the sludges was included on the pink cards

Several conclusions are apparent from the data in Table 7:

- The previously-reported number of sludge drums in Trench 73 (zero) is confirmed to be an error, because the Group I sludge activity from the 39 cards correlates with the 0.7 mCi previously reported for this trench. We now know that the EHM summary only reported Group I activity when sludge drums were present. Thus, the incorrect zero has been greyed out.
- The reported Group I activity in Trench 75 (8.1 mCi, see Appendix E) is almost certainly a transcription error. This error (~40% of total Group I activity) counterbalances to some extent the omission of the activity content of the earlier trenches in the EHM document.
- For most of these trenches, the Group I content of the sludge drums accounts for the majority of the Group I activity reported in the previous record. However, there must have been other contributors to the Group I activity in Trenches 71 and 76 (for which the EHM summary data somewhat exceed the amounts on the available pink cards). The cards for these additional items appear to have been lost.
- There is a significant contribution from the non-sludge pink cards to Group I in Trench 72 because of the presence of some Pu items reported on an SDR. These amounts were not included in previous summaries.
- The distribution of activity between the trenches is somewhat different to previous summaries, (for example for Group III in Trench 73). This is likely partly because the pink card record has become confused (these cards have not been systematically stored and labelled).

- The amounts shown as “total activity” in Groups I, II and III (blue boxes) are similar between the two compilations. We believe this is a useful indicator of the degree of trust that can be placed in the available records: they are indicative but neither comprehensive nor completely accurate. In fact, in this specific example some known sources of under- and over-estimates cancel each other out.

Despite the effort put into this exercise, considerable uncertainties remain about the contents of these specific trenches, and also the relative contribution of the sludges (and other items) to the radionuclide inventory at LFLS. Regardless of the amount of time invested in interpreting the pink cards (also see Chapter 8), they remain a fragmentary and limited source of information. It is unlikely that further efforts along these lines will ever provide a fully authoritative record.

6.4. Later estimates of sludge drum contents

The importance of the contents of the sludge drums was realised after the disposals at LFBG had ceased. This was discussed at length in a subsequent report (Isaacs and Mears, 1977), however the report contained no information on alpha-emitters or Group I radionuclides. Instead this report focused on the shorter-lived isotopes such as Sr-90, Cs-137 and Co-60 (see Section 10.2).

During the course of the present project, a significant set of data on the radionuclide content of some stored sludge drums was reviewed. These drums had been stored since around 1970 (i.e. commencing with drums filled around the time when disposals ceased). These data will be considered in a subsequent report (E-789).

6.5. Effect of sludges and SDRs on amounts of Group I activity

The previous summaries of the radionuclide inventory at LFLS have grouped the radionuclides between Groups I, II and III (with Group I being the most hazardous, see Section 5.4.1). The exhaustive survey of the records undertaken in the present project has shown that the inventory of Group I radionuclides has been greatly underestimated in previous reports (AAEC, 1985; Payne, 2012). The Group I data are summarised in Table 8. The reported inventory of Group I radionuclides (approximately 0.75 GBq) only represents about 4% of the actual inventory. While the majority of the additional inventory is derived from the Pu content in the known SDR items, the omission of approximately 75% of the sludge drums from the inventory also makes a significant contribution. However, it is important to note that the disposal of gram quantities of Pu at the LFLS has been previously acknowledged, and the discrepancy (summarised in Table 8) is mainly due to the under-reporting of Group I activity.

As mentioned above, there is one operational record (from 1968) which provides a similar estimate of the Group I inventory to the one we propose in the present report. An extract from this record is shown in Figure 28. Unfortunately, subsequent reports (until now) have repeated the incorrect lower figure from the EHM document.

The fact that the Group I radionuclides have been previously under-reported is a significant finding, because this group contains some long-lived radionuclides that will persist in the environment for very long periods. However, the hazard at LFLS is not directly related to the amounts of Group I radionuclides present. As we have noted, the groupings used actually combine radionuclides into various categories, and the long-term impact of the site can only be evaluated from the inventories of individual radionuclides (which are difficult to estimate) and subsequent dose-modelling (Johansen et al., 2020).

Table 8. Distribution of Activity of Group I radionuclides between reported and newly estimated categories

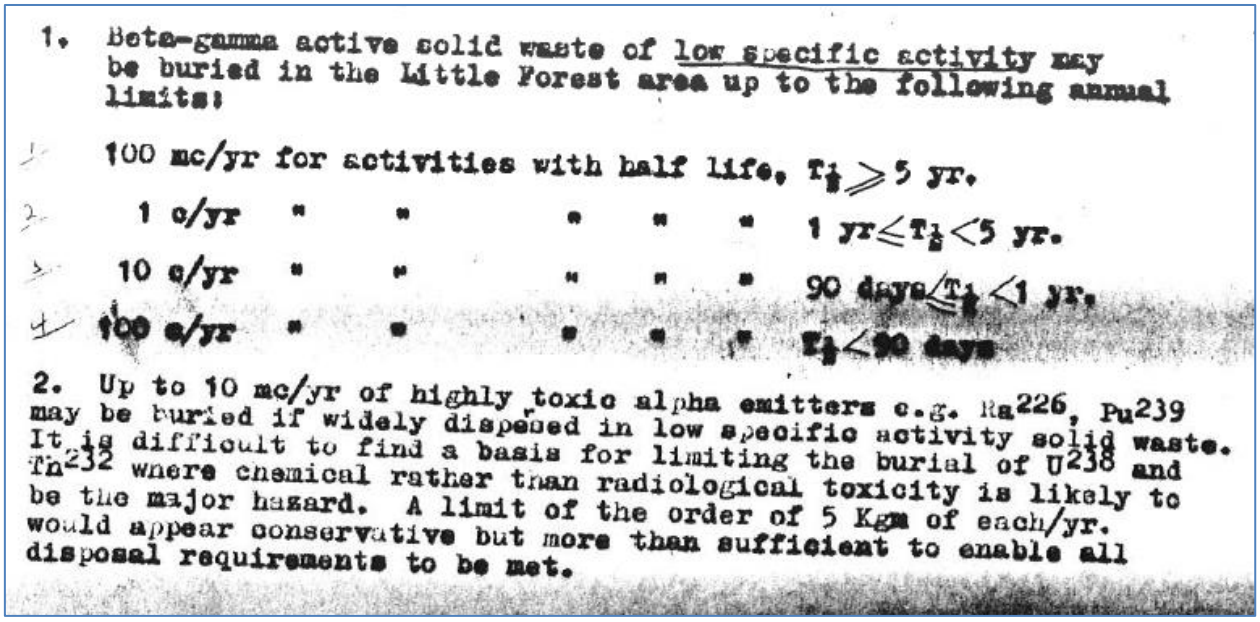
Previously reported activity	**Activity in SDRs (GBq) (**Table 5**)**	**Additional sludge activity (Trenches before T71)**	**Total**
0.75 GBq	19.1 GBq	~2.25 GBq	~22 GBq
4 %	87 %	9 %	Distribution

7. Events, deliberations and decisions during the disposal period

The purpose of this section is to document some decisions and operational practices that occurred during the operational period of the LFBG that directly or indirectly influenced the disposal operations and may provide further contextual information relevant to the contents of the LFBG trenches. We examine various operational limits on the activity that could be disposed and the fissile materials emplaced at the LFBG, as well as the sources and disposal of specific items (including dispersible beryllium). We also consider some of the factors that may have led to the cessation of disposal operations at the LFBG.

7.1. Limits of radioactivity that could be disposed

At the start of the operations of the LFBG a request was made (in late 1961) for a statement of limits of waste that could be disposed at the LFBG. The limits that were specified in 1961 are shown in Figure 36. The permissible amount of disposed radionuclides depended on their half-life and was based on their activity (measured in Curies, Ci). In the documents of the time, the unit Curie (Ci) was often abbreviated as a lower case "c" (rather than Ci). It can be seen that the limit for "highly toxic alpha emitters" (including Pu-239) was "up to 10 mCi/year". In the case of plutonium, this would be less than 0.2 g. Increased limits were subsequently proposed (Figure ***37***).



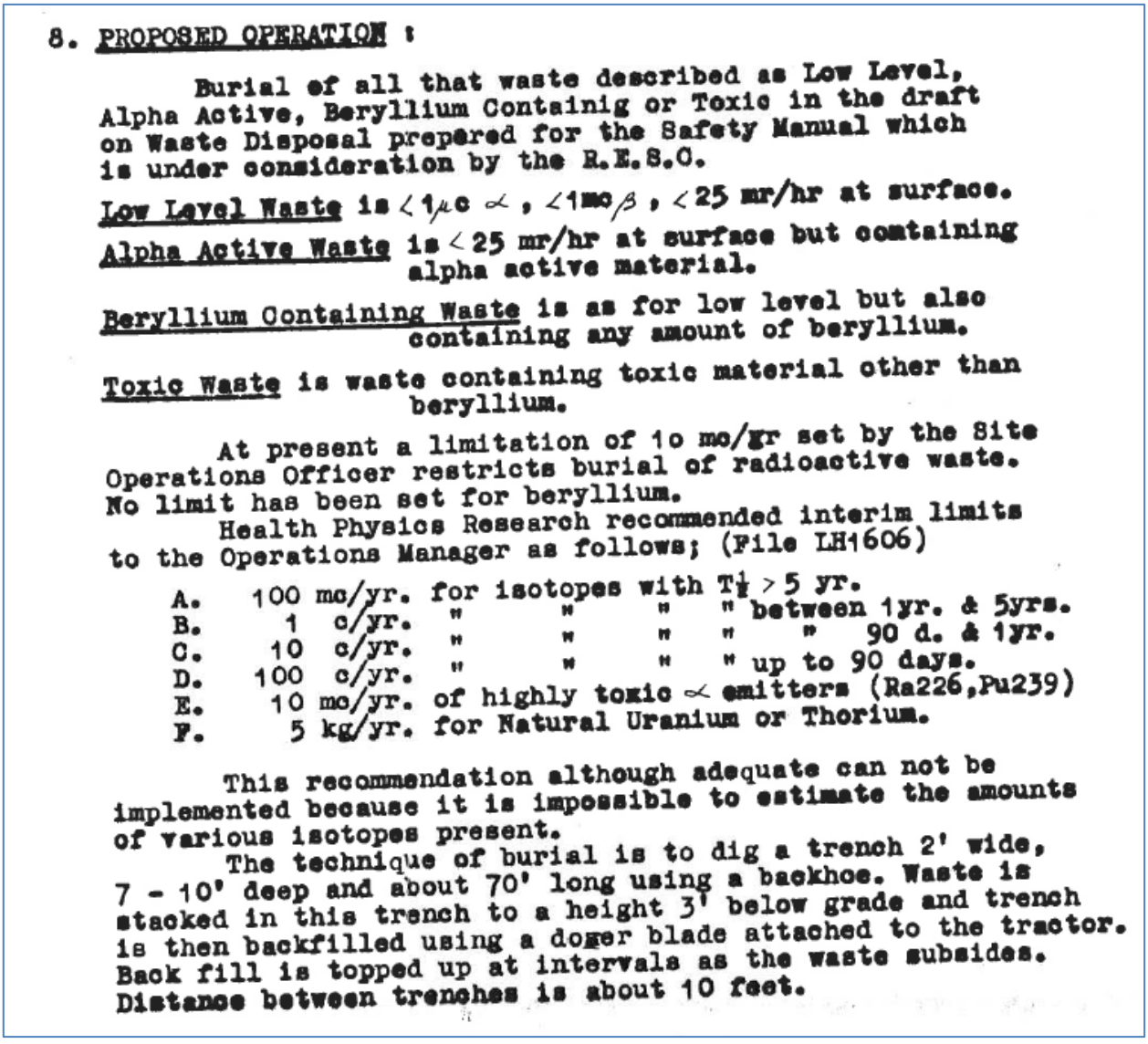
1. Beta-gamma active solid waste of low specific activity may be buried in the Little Forest area up to the following annual limits:

1. 100 mc/yr for activities with half life, $T_{\frac{1}{2}} \geqslant 5$ yr.
2. 1 c/yr " " " " " 1 yr $\leqslant T_{\frac{1}{2}} < 5$ yr.
3. 10 c/yr " " " " " 90 days $\leqslant T_{\frac{1}{2}} < 1$ yr.
4. 100 c/yr " " " " " $T_{\frac{1}{2}} < 90$ days

2. Up to 10 mc/yr of highly toxic alpha emitters e.g. Ra^{226}, Pu^{239} may be buried if widely dispersed in low specific activity solid waste. It is difficult to find a basis for limiting the burial of U^{238} and Th^{232} where chemical rather than radiological toxicity is likely to be the major hazard. A limit of the order of 5 Kgm of each/yr. would appear conservative but more than sufficient to enable all disposal requirements to be met.

Figure 36. The proposed limit of beta-gamma active solid waste and "highly toxic alpha emitters" would only allow disposal of less than 0.2 g of Pu per year (10 mCi).

Although a dose-limit for disposed wastes may not have been specified at the start of disposal operations, the EHM document (Figure 38) indicated that the applicable limit for the early years (until SAP/P5) was 5 mR/hour. This 5 mR/hr dose rate limit probably applied for much of the disposal period. It appears that an increase of this limit (to 25 mR/hr) was proposed in a request for safety committee approval for disposal operations (dated 22 July, 1964). An interesting aspect of this document (Figure ***37***) is a clear statement that the activity limits could not be implemented because it was "impossible to estimate the amounts of various isotopes present". This indicates considerable operational difficulties associated with the radioactive waste disposals at the LFBG, both in terms of defining the applicable dose limits as well as estimating the actual activities disposed. The records indicate that this proposal to raise the dose-rate limit to 25 mR/hr was first approved, then rescinded by the Safety Committee during its deliberations in August 1964.



8. PROPOSED OPERATION :

Burial of all that waste described as Low Level, Alpha Active, Beryllium Containig or Toxic in the draft on Waste Disposal prepered for the Safety Manual which is under consideration by the R.E.S.C.

Low Level Waste is $< 1\mu c\ \alpha$, $< 1mc\ \beta$, < 25 mr/hr at surface.

Alpha Active Waste is < 25 mr/hr at surface but containing alpha active material.

Beryllium Containing Waste is as for low level but also containing any amount of beryllium.

Toxic Waste is waste containing toxic material other than beryllium.

At present a limitation of 10 mc/gr set by the Site Operations Officer restricts burial of radioactive waste. No limit has been set for beryllium.

Health Physics Research recommended interim limits to the Operations Manager as follows; (File LH1606)

A.	100 mc/yr.	for isotopes with $T_{\frac{1}{2}} > 5$ yr.
B.	1 c/yr.	" " " " between 1yr. & 5yrs.
C.	10 c/yr.	" " " " " 90 d. & 1yr.
D.	100 c/yr.	" " " " up to 90 days.
E.	10 mc/yr.	of highly toxic α emitters (Ra226,Pu239)
F.	5 kg/yr.	for Natural Uranium or Thorium.

This recommendation although adequate can not be implemented because it is impossible to estimate the amounts of various isotopes present.

The technique of burial is to dig a trench 2' wide, 7 - 10' deep and about 70' long using a backhoe. Waste is stacked in this trench to a height 3' below grade and trench is then backfilled using a doger blade attached to the tractor. Back fill is topped up at intervals as the waste subsides. Distance between trenches is about 10 feet.

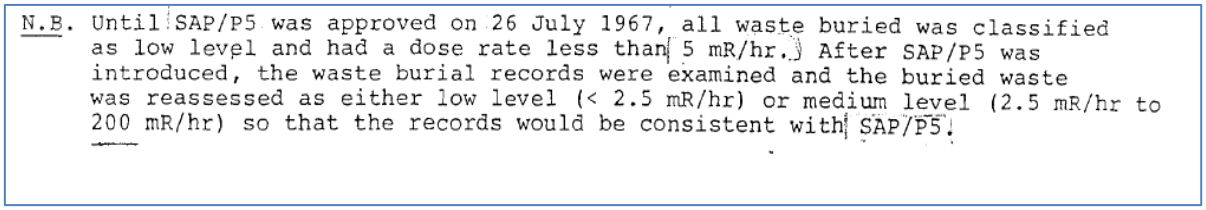
Figure 37***. A document (from 1964) proposing an increased surface dose rate (25 mR/hr) for disposed items. The activity amounts were the same as previously propagated (Figure 36). Note the statement that the activity limits cannot be implemented because it is "impossible to estimate the amounts of various isotopes present".***

7.2. Disposal limits applicable after SAP / P5

According to the available summaries, the disposed activity in Trenches 67 and subsequent trenches greatly exceeded those in previous trenches. Undoubtedly, the main reason for the increase in activity disposed was due to the adoption of the proposals in the SAP/P5 document (Bonhote, 1967). This made possible the disposal of items with an activity of up to 200 mR / hr. According to the EHM document, all waste which was buried before the approval of SAP/P5 (on 26 July 1967) was classified as low level and had a dose rate less than 5 mR/hr (Figure 38).

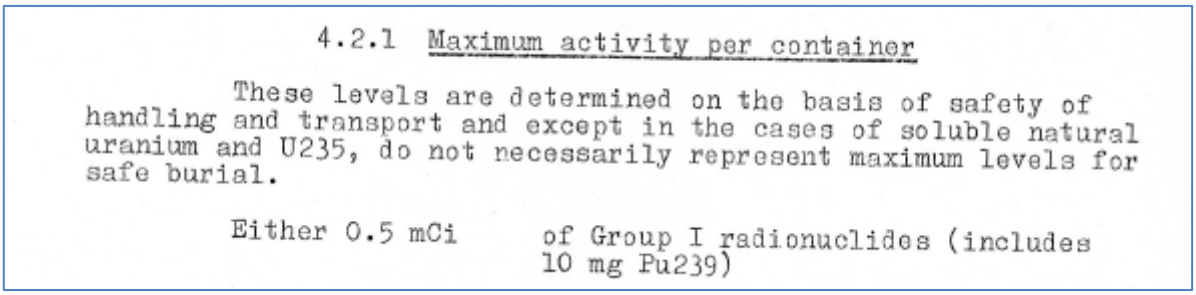
Therefore, the proposals in SAP/P5 raised the allowable dose rate to 200 mR / hr, a factor of 40 higher than had previously applied. The activity disposed was estimated from the surface dose rate, hence the greater doses on the later items translated into higher estimates for disposed activity. Another relevant factor was the emptying out of the burial ground store during this period. The store had been used to enable the decay of short-lived activity, therefore the stored items tended to be the most active ones. Finally, another possible factor leading to the higher amounts of activity in the final trenches filled was that the disposal team may have been aware of the upcoming cessation of disposals and accelerated the rate of disposal for this reason.

The SAP/P5 document proposed a limit of 10 mg of Pu per package (Figure 39). It is not clear whether this was a response to previous disposals of greater amounts of Pu (such as the items in SDR 35). It should be noted that by the time of SAP/P5 the most significant Pu packages had already been disposed. Relatively small amounts of Pu were disposed during 1968.



N.B. Until SAP/P5 was approved on 26 July 1967, all waste buried was classified as low level and had a dose rate less than 5 mR/hr. After SAP/P5 was introduced, the waste burial records were examined and the buried waste was reassessed as either low level (< 2.5 mR/hr) or medium level (2.5 mR/hr to 200 mR/hr) so that the records would be consistent with SAP/P5.

Figure 38. Extract from the EHM document, which indicated that the approval of SAP/P5 raised the allowable dose-rate for disposal from 5 mR / hour to 200 mR/hr.



4.2.1 Maximum activity per container

These levels are determined on the basis of safety of handling and transport and except in the cases of soluble natural uranium and U235, do not necessarily represent maximum levels for safe burial.

Either 0.5 mCi of Group I radionuclides (includes 10 mg Pu239)

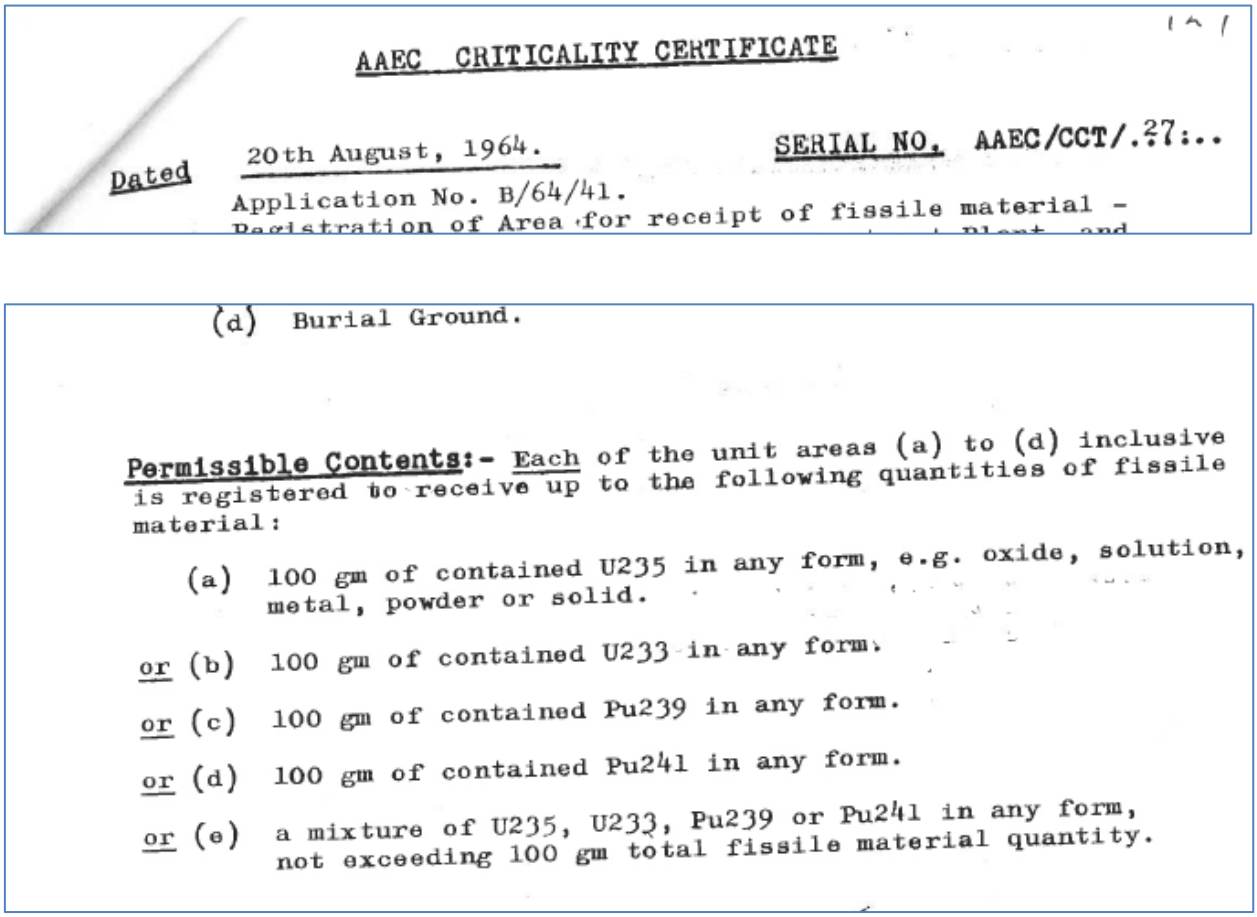
Figure 39. Extract from the SAP/P5 document, indicating a limit of 10 mg of Pu-239 per container. This amount is much lower than some of the packages which had been previously disposed, for example the item in SDR 35 (shown in Figure 15) which contained 3.7 g of plutonium.

7.3. Criticality and SDRs

The situation regarding disposals became more complex in 1964 when the burial ground was issued with a “Criticality Certificate”. These types of certificates were intended to prevent accumulations of potentially critical amounts of fissile isotopes in any given area. The amount of U-233 and plutonium specified on the issued certificate (Figure 40) far exceeded the then-existing disposal limits which were based on radioactivity (discussed above). The criticality certificate (dated 20th August, 1964) allowed a total of up to 100 g of plutonium to be received at the burial ground, in any form.

It is possible that the criticality certificate had the unintended consequence of legitimising disposals of Pu at LFBG which exceeded the limits mentioned in the existing safety approvals. The Criticality Limits were relaxed even further the following year, whereby the “Criticality Officer” informed the “Waste Operations” section that even larger amounts could be disposed (up to 100 g per trench, rather than 100 g for the entire site). The revised advice on criticality limits (Figure 41) was issued on 21 December 1965.

A notable feature of the criticality certificate (Figure 40) is the inclusion of Pu-241 (up to 100 gm) in the list of permitted disposals. This is significant because it is one of the few times that Pu-241 was mentioned in the list of disposed (or potentially disposed) isotopes. This recognition of the possible disposal of this isotope at the LFBG is relevant given the subsequent detections of Am-241 in environmental samples at the site. It is also worth noting that 100 gm of Pu-241 (had it been disposed) would have comprised a very large amount of activity, and would have made a major contribution to the inventory of Group I radionuclides at the site.



AAEC CRITICALITY CERTIFICATE

Dated 20th August, 1964. SERIAL NO. AAEC/CCT/.27:..

Application No. B/64/41.

Registration of Area for receipt of fissile material -

(d) Burial Ground.

Permissible Contents:- Each of the unit areas (a) to (d) inclusive is registered to receive up to the following quantities of fissile material:

(a) 100 gm of contained U235 in any form, e.g. oxide, solution, metal, powder or solid.

or (b) 100 gm of contained U233 in any form.

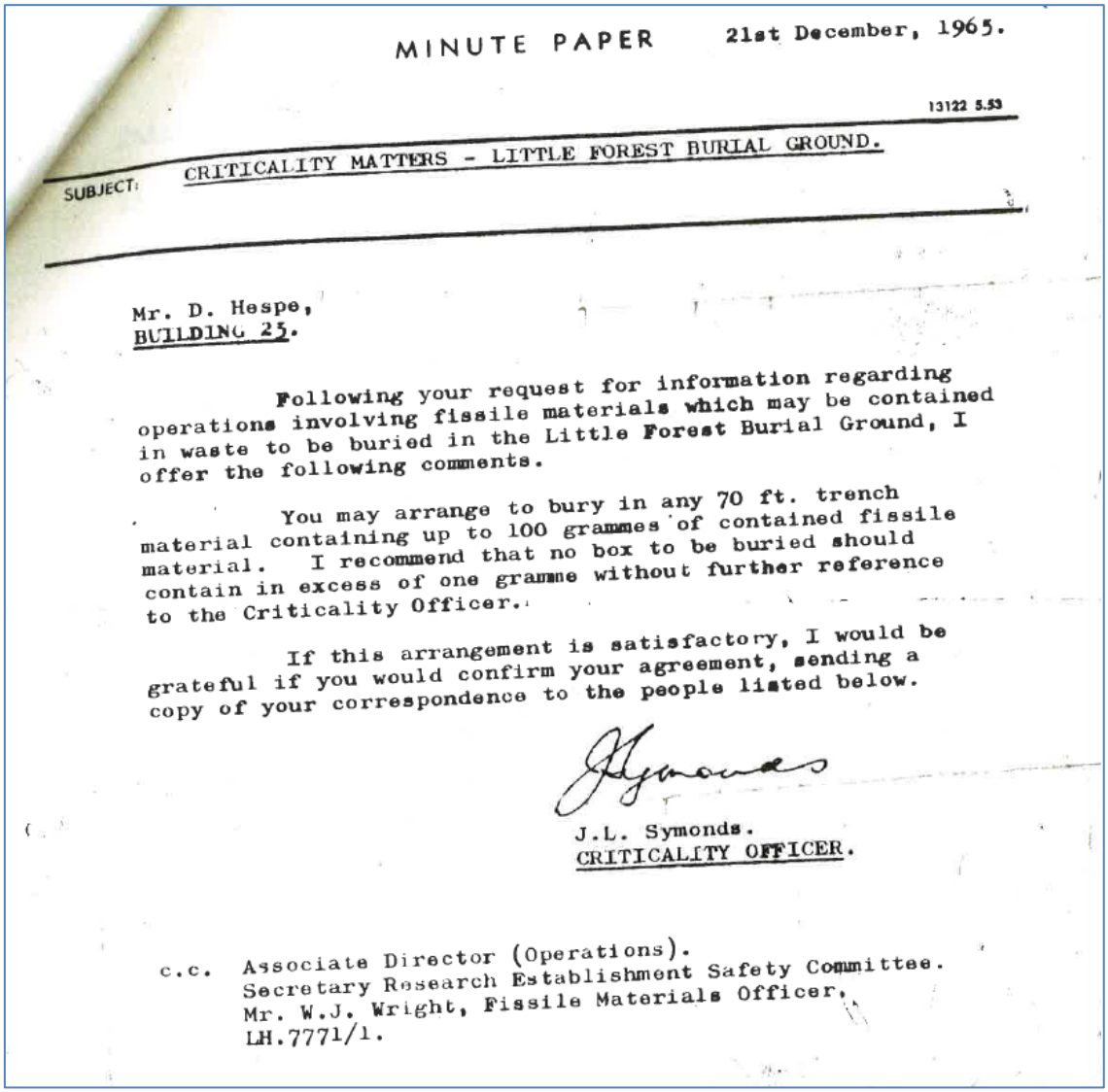
or (c) 100 gm of contained Pu239 in any form.

or (d) 100 gm of contained Pu241 in any form.

or (e) a mixture of U235, U233, Pu239 or Pu241 in any form, not exceeding 100 gm total fissile material quantity.

Figure 40. A criticality certificate which permitted disposal of mixtures of fissile materials (U-235, U-233, Pu-239 and Pu-241), up to 100 grams in total, at the LFBG.

There is no evidence the limits specified in the criticality documents were ever approached (in other words, no trench at LFBG ever received 100 grams of fissile material). Such an amount would have considerably exceeded the permitted amounts specified in the SAC approval for waste disposal. However, the first disposal of gram quantities of plutonium, which occurred in Trench 53 on 23 December 1965, may have been a direct consequence of the issuing of the second criticality certificate 2 days earlier (Figure 41). The sequence of events suggests considerable urgency and possibly lack of consideration of the consequences of the decision to dispose of the increased amounts of plutonium. The proximity to the Christmas period may have increased the pressure to complete the disposals.



MINUTE PAPER 21st December, 1965.

13122 5.53

SUBJECT: CRITICALITY MATTERS - LITTLE FOREST BURIAL GROUND.

Mr. D. Hespe,
BUILDING 25.

Following your request for information regarding operations involving fissile materials which may be contained in waste to be buried in the Little Forest Burial Ground, I offer the following comments.

You may arrange to bury in any 70 ft. trench material containing up to 100 grammes of contained fissile material. I recommend that no box to be buried should contain in excess of one gramme without further reference to the Criticality Officer.

If this arrangement is satisfactory, I would be grateful if you would confirm your agreement, sending a copy of your correspondence to the people listed below.

J.L. Symonds.
CRITICALITY OFFICER.

c.c. Associate Director (Operations).
Secretary Research Establishment Safety Committee.
Mr. W.J. Wright, Fissile Materials Officer.
LH.7771/1.

Figure 41. A minute paper (December 1965) which increased the allowable amounts of fissile material to be disposed in individual trenches at LFBG (the limits were changed from applying to the entire burial ground to the contents of individual trenches).

7.4. Operations in key laboratories and facilities

The activities occurring in a number of locations on the Lucas Heights site resulted in the disposal of specific radionuclides. The origins (i.e. room/laboratory/building) of the LFBG wastes (which were noted on both the pink cards and the burial books) can therefore provide information on the radionuclides disposed.

Plutonium seems to have been handled to the greatest extent in the following rooms:

- Building 2 (Rm 166)
- Building 2 (Rm 167)
- Building 3 (Rm 151), which was the source of biggest known item of Pu (in Trench 55).
- Building 19 (Rm 16), the source of Pu items in Trench 53.
- Building 2 (Rm 187)
- Building 2 (CEMBAY, CEMB)
- Building 3 (Rm 112)

Later the decontamination centre was also a significant source of Pu containing items

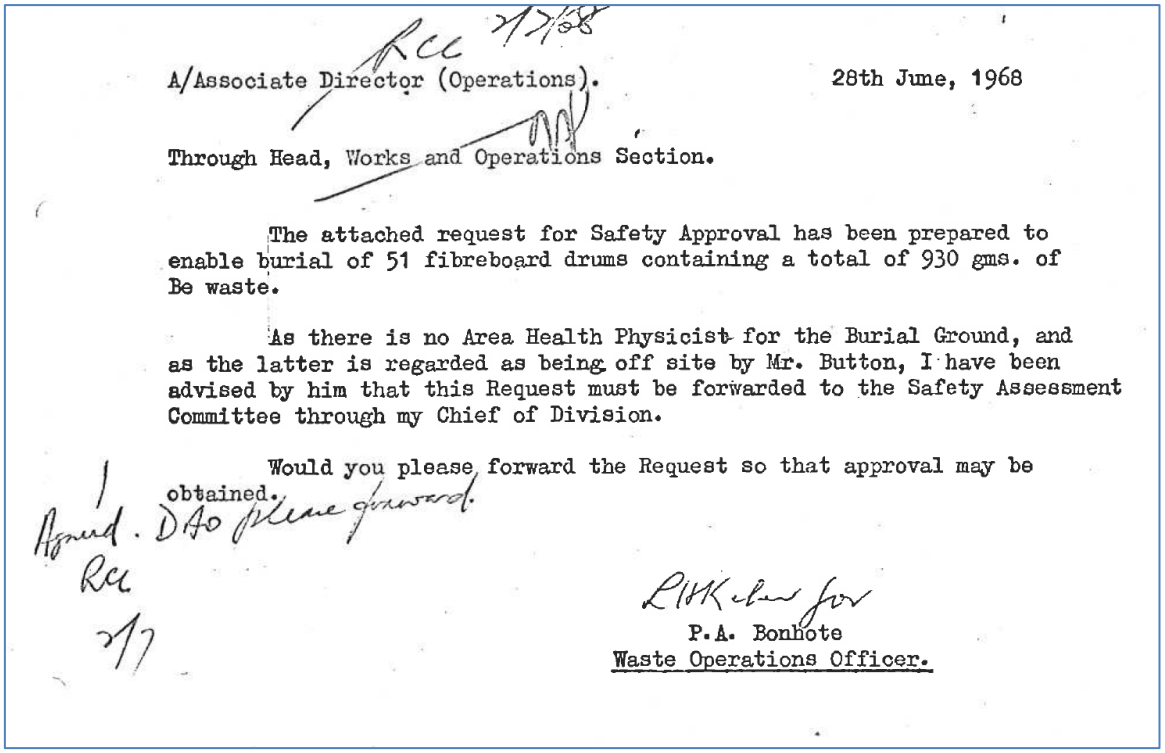
U-233 was apparently handled in B2, in a facility known as the CEMB. The package (labelled Item F 6-68) with the highest single recorded amount of U-233 (2.23 g) originated there and was subsequently buried in Trench 67 (Figure 16). Some significant Uranium-235 items also came from B19, room Y28.

7.5. The disposal of dispersible beryllium in Trench 73.

In May 1958, the government had approved a new construction program at Lucas Heights, including a building for fabrication of beryllium fuels, which required special handling facilities on account of the toxicity of beryllium and beryllium oxides. At the time, key staff-members were considering the dangers associated with beryllium. One AAEC staff-member (Dr R.B. Temple) reported that it is “probably the most toxic non-radioactive material that we shall encounter at Lucas Heights”. While it was clear that beryllium was a serious inhalation hazard, there were notable gaps in the published data on its toxicity. Based on the available information, Dr Temple concluded that it was “by far the most toxic to fish of the metallic poisons” (see discussion in Payne (2015)).

The dispersible powder form is particularly hazardous. One of the most significant disposal events at LFBG was the burial of 930 g of dispersible beryllium in Trench 73 (Figure 42 and Figure 43). This beryllium was associated with the multiple packages (51 fibreboard drums) which were approved by a special SAC submission. Some were indicated as originating from the BeO sphere manufacturing program. Although the reference to 1.723 Kg as the total amount of beryllium in Trench 73 (Figure 43) was correct, this 1983 document failed to clarify that, based on WBR 73, this trench also included 0.793 kg of beryllium from “normal waste” (i.e. other disposed items) as well as the 930 g of dispersible Be referred to in Figure 42. This type of discrepancy is often found in the available LFLS records.

While this specific batch of less than 1 Kg of dispersible beryllium placed in Trench 73 was apparently of particular significance, it appears that, in total, several hundred kilograms of beryllium were disposed in some form of powder (Figure 28).



A/Associate Director (Operations). 28th June, 1968

Through Head, Works and Operations Section.

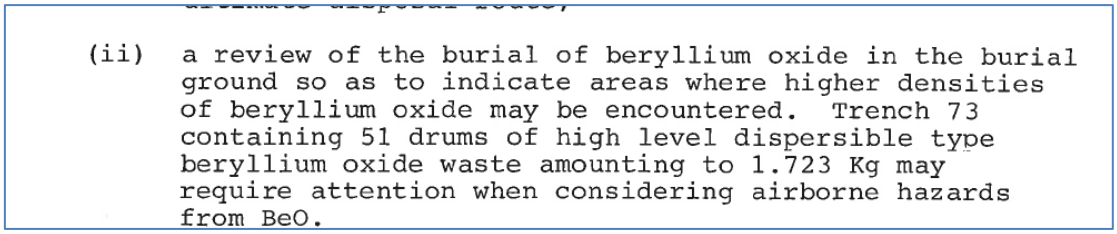
The attached request for Safety Approval has been prepared to enable burial of 51 fibreboard drums containing a total of 930 gms. of Be waste.

As there is no Area Health Physicist for the Burial Ground, and as the latter is regarded as being off site by Mr. Button, I have been advised by him that this Request must be forwarded to the Safety Assessment Committee through my Chief of Division.

Would you please forward the Request so that approval may be obtained.

P.A. Bonhote
Waste Operations Officer.

Figure 42. The dispersible beryllium in Trench 73 was disposed of with a special SAC approval (SAC 68/17) dated June 28, 1968.



(ii) a review of the burial of beryllium oxide in the burial ground so as to indicate areas where higher densities of beryllium oxide may be encountered. Trench 73 containing 51 drums of high level dispersible type beryllium oxide waste amounting to 1.723 Kg may require attention when considering airborne hazards from BeO.

Figure 43. A document from 1983 referred to the hazards of beryllium disposed in Trench 73.

7.6. Waste disposals for outside organisations

As noted in a previous report (Payne, 2015) the issue of disposal of waste for other institutions emerged in the late 1950's and would later become a significant question for the AAEC during the operational period of the LFBG. The earliest external disposal request on record originated from Sydney University, in December 1958[20], prior to the commencement of operations at LFBG, and it was decided that the AAEC was not yet in a position to help with disposal. However, after the LFBG became operational, radioactive wastes were disposed for external clients, including various universities, Commonwealth Scientific and Industrial Research Organisation (CSIRO), the navy, and hospitals. The AAEC expected to derive some income from these disposals.

[20] IJW Bissett, File Minute, 22 December 1958.

Examples include:

- Disposal of Co-60 and radium in March 1964 for the Navy.
- Disposal of 10 x 44 gallon drums of uranium ore from the University of NSW in Trench 38

While these disposals were intended to generate external revenue for the AAEC, they had the disadvantage that space was limited at the burial ground. Furthermore, the documentation of the received waste could be inadequate or missing.

Although seen as an attractive commercial proposition by some staff at the AAEC, the disposal of external waste was also perceived as a potential problem. For example, one internal minute (dated 28 August 1968) noted that waste (from South Australia) would be travelling through several states, and these jurisdictions would require their own transport requirements to be met. The AAEC therefore adopted a policy of not accepting responsibility for the waste until it arrived.

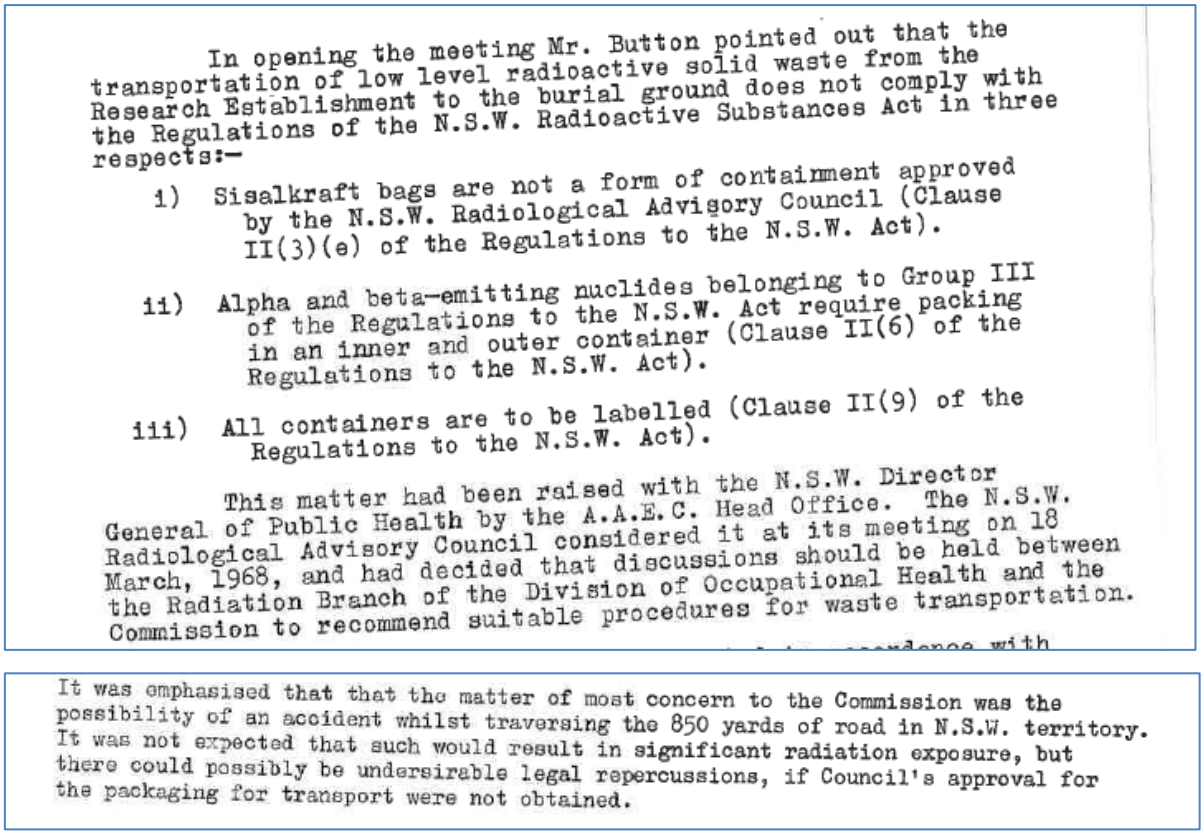
7.7. Evidence that unknown items were disposed

As noted above, the LFBG was used for disposal of wastes for outside organisations. These included commercial organisations, hospitals, universities, the Navy and the CSIRO. A hand-written document (dated 9 May 1967) clearly states that disposals would be cheaper if the wastes from external organisations arrived when a trench was open (rather than requiring storage). Under these circumstances, it seems possible that the composition of disposed items would not be reported within the waste disposal record system used for AAEC disposals.

On 25 October 1968, an AAEC staff-member (Mr L.H. Keher) expressed concern about some spent sources from the RAAF which had been delivered and were then disposed. He was particularly concerned there was nothing on file to document these disposals. A senior staff member added a comment that procedures should be implemented so this did not happen again. It may well be that tensions arising from this incident contributed to the senior management becoming increasingly concerned about continuing the disposal operations. As events turned out, the entire disposal operation ceased at LFBG less than a month later, after the filling of Trench 76.

7.8. Traffic issues and frictions with NSW state authority for radioactive transport

In 1968 the transport of waste to the LFBG was becoming an increasing source of contention with the state authorities. The applicable requirements were discussed in a meeting of the NSW Radiological Advisory Council on 11 June 1968 (Figure 44). The minutes of this meeting clearly show that the AAEC was aware that the transport arrangements for the waste did not comply with the applicable NSW regulations. Although the transport distance was less than a kilometre and the AAEC may have been exempt from state regulations, this situation was clearly undesirable and the AAEC was aware of the potential for “legal repercussions” should an accident occur.



In opening the meeting Mr. Button pointed out that the transportation of low level radioactive solid waste from the Research Establishment to the burial ground does not comply with the Regulations of the N.S.W. Radioactive Substances Act in three respects:—

i) Sisalkraft bags are not a form of containment approved by the N.S.W. Radiological Advisory Council (Clause II(3)(e) of the Regulations to the N.S.W. Act).

ii) Alpha and beta-emitting nuclides belonging to Group III of the Regulations to the N.S.W. Act require packing in an inner and outer container (Clause II(6) of the Regulations to the N.S.W. Act).

iii) All containers are to be labelled (Clause II(9) of the Regulations to the N.S.W. Act).

This matter had been raised with the N.S.W. Director General of Public Health by the A.A.E.C. Head Office. The N.S.W. Radiological Advisory Council considered it at its meeting on 18 March, 1968, and had decided that discussions should be held between the Radiation Branch of the Division of Occupational Health and the Commission to recommend suitable procedures for waste transportation.

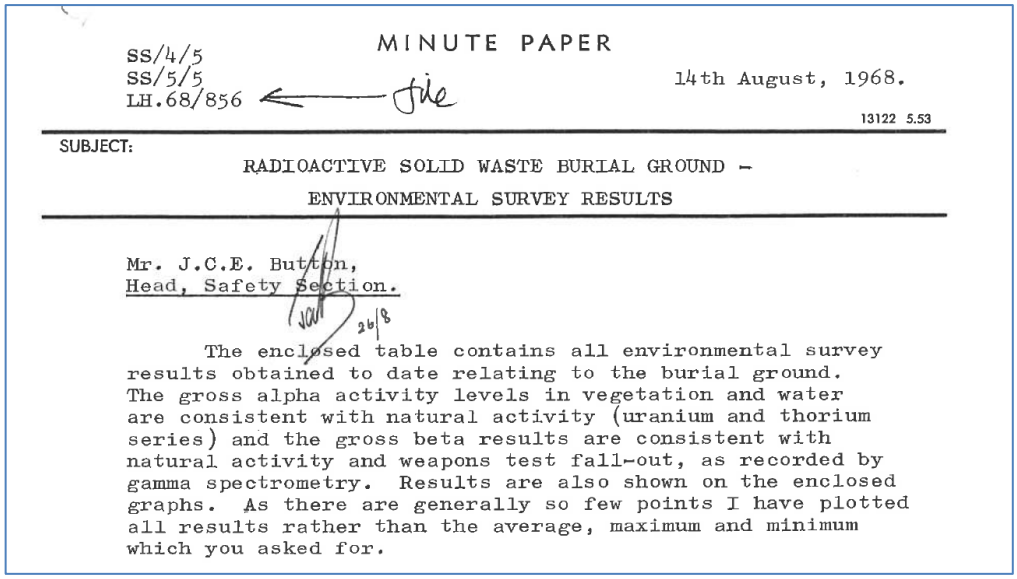
It was emphasised that that the matter of most concern to the Commission was the possibility of an accident whilst traversing the 850 yards of road in N.S.W. territory. It was not expected that such would result in significant radiation exposure, but there could possibly be undesirable legal repercussions, if Council's approval for the packaging for transport were not obtained.

Figure 44. Various extracts from the discussions with the NSW Radiological Advisory Council of 11 June 1968, indicating difficulties associated with the packaging of the wastes for transport to the burial ground.

7.9. Commencement of environmental monitoring

Relatively few environmental samples of soil or water were taken for radionuclide measurements at the LFBG before January 1967, when an annual survey commenced (some vegetation samples had been previously analysed). A minute paper from Mr J.E. Cook to the head of the safety section summarised the data existing at that time (Figure 45). However, the environmental sampling did not meet the approval of the then acting deputy director of the AAEC (Dr G.L. Miles). In a scathing assessment dated 3 October 1968, he expressed the opinion that the system of sampling was unsatisfactory and the results were meaningless (Figure 46). The Minute from the Acting Deputy Director contained a request to undertake drilling and institute a regular 6-monthly sampling program. However, the tone of Mr Miles comments was so negative that R.C. Cairns asked the question “should we continue to bury” in a hand-written annotation to the original minute. It is clear that the perceived inadequacies of the previous environmental monitoring were of major concern to the senior AAEC leadership and were possibly a contributing factor in the cessation of disposals a few months later.

These events led to the commencement of regular environmental monitoring of the site, which has been continuously undertaken and reported for more than five decades.



MINUTE PAPER

SS/4/5
SS/5/5
LH.68/856 ← file

14th August, 1968.

13122 5.53

SUBJECT:

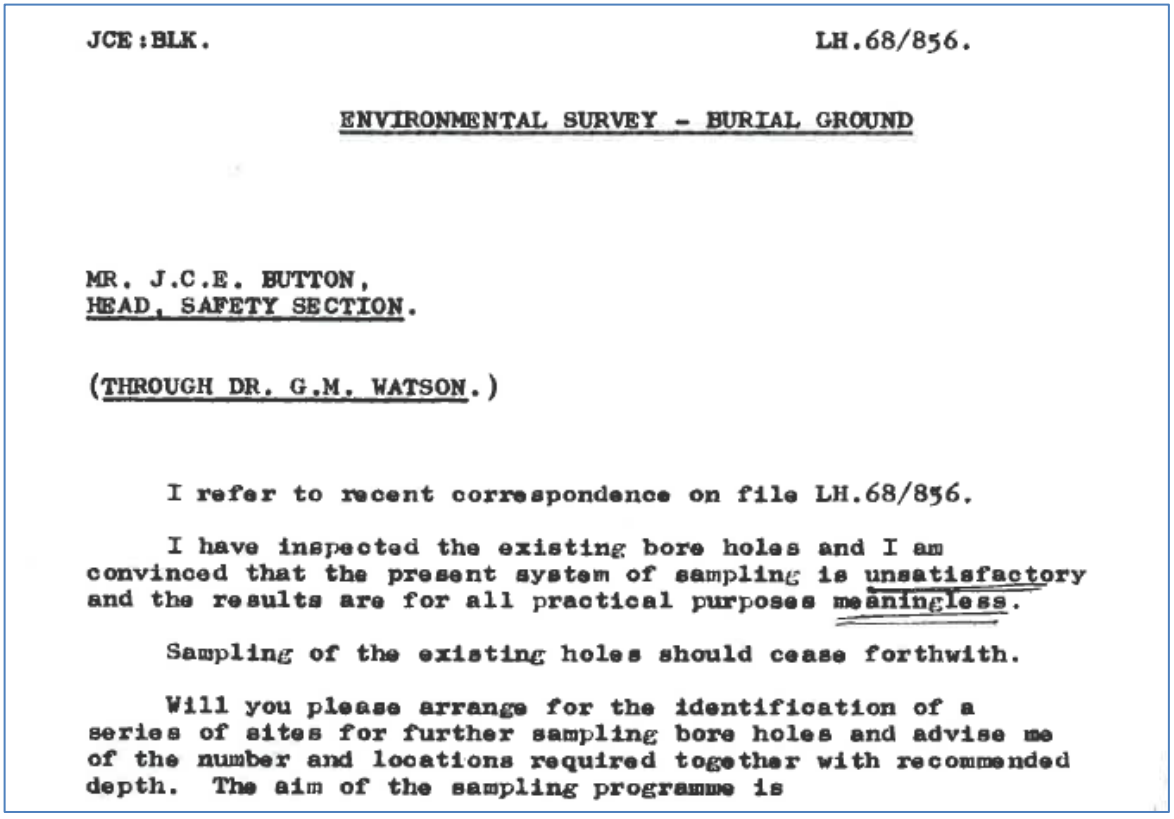
RADIOACTIVE SOLID WASTE BURIAL GROUND -
ENVIRONMENTAL SURVEY RESULTS

Mr. J.C.E. Button,
Head, Safety Section.

JCB 26/8

The enclosed table contains all environmental survey results obtained to date relating to the burial ground. The gross alpha activity levels in vegetation and water are consistent with natural activity (uranium and thorium series) and the gross beta results are consistent with natural activity and weapons test fall-out, as recorded by gamma spectrometry. Results are also shown on the enclosed graphs. As there are generally so few points I have plotted all results rather than the average, maximum and minimum which you asked for.

Figure 45. Extracts from a minute dated 14 August 1968 discussing data for a few vegetation samples that were taken between 1960 and 1963, as well as samples of water which had been obtained in January 1967 and January 1968 from boreholes on the site.



JCE:BLK. LH.68/856.

ENVIRONMENTAL SURVEY - BURIAL GROUND

MR. J.C.E. BUTTON,
HEAD, SAFETY SECTION.

(THROUGH DR. G.M. WATSON.)

I refer to recent correspondence on file LH.68/856.

I have inspected the existing bore holes and I am convinced that the present system of sampling is unsatisfactory and the results are for all practical purposes meaningless.

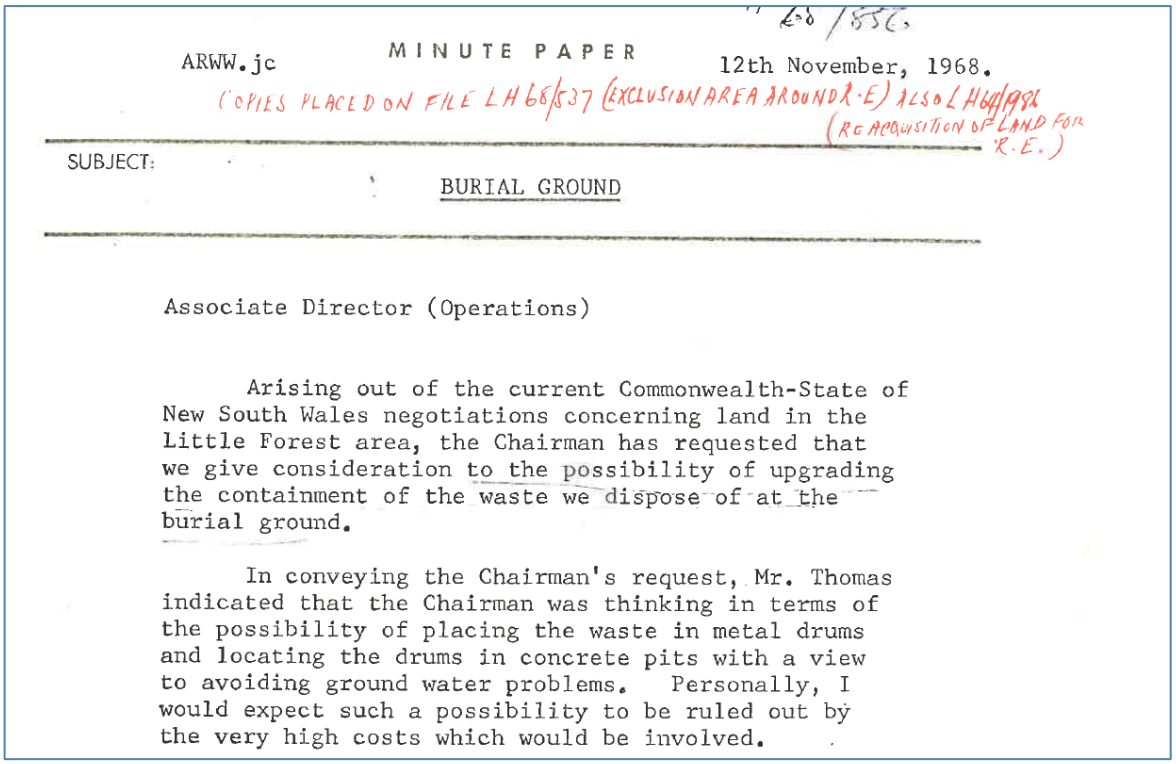
Sampling of the existing holes should cease forthwith.

Will you please arrange for the identification of a series of sites for further sampling bore holes and advise me of the number and locations required together with recommended depth. The aim of the sampling programme is

Figure 46. Minute from G. L. Miles describing the environmental sampling as 'unsatisfactory' and the results as 'meaningless'. He suggested a greatly improved sampling network and regular sampling at the site. This recommendation was implemented.

7.10. Discussions about improved waste containment

Another consideration in late 1968 was that various discussions (including those with the NSW Radiological Advisory Council) had led to questions being asked about whether the disposal methods used at LFBG were adequate. These concerns were exemplified in a minute from 12 November 1968, whereby the issue of upgrading the containment of disposed wastes was raised (Figure 47). This document (and similar documents from the period) clearly indicate potential shortcomings of the disposal procedures then in use.



ARWW.jc MINUTE PAPER 12th November, 1968.

COPIES PLACED ON FILE LH 68/837 (EXCLUSION AREA AROUND A.E.) ALSO LH 68/982 (RE ACQUISITION OF LAND FOR A.E.)

SUBJECT: BURIAL GROUND

Associate Director (Operations)

Arising out of the current Commonwealth-State of New South Wales negotiations concerning land in the Little Forest area, the Chairman has requested that we give consideration to the possibility of upgrading the containment of the waste we dispose of at the burial ground.

In conveying the Chairman's request, Mr. Thomas indicated that the Chairman was thinking in terms of the possibility of placing the waste in metal drums and locating the drums in concrete pits with a view to avoiding ground water problems. Personally, I would expect such a possibility to be ruled out by the very high costs which would be involved.

Figure 47. A minute from the acting director of the AAEC raising the possibility of upgrading waste containment at the LFBG.

7.11. Factors contributing to the cessation of disposal operations

The available evidence shows that a number of concerns had arisen with the LFBG operations during 1968, including:

- Several incidents indicating that waste disposals were poorly documented and that unauthorised disposals had occurred. This issue is relevant to the evaluation of the LFBG inventory.
- The method of transporting waste to the site, which involved roads outside the jurisdiction of the AAEC.
- Concerns that the disposal of waste by burial of packages in unlined trenches was not adequate and improved methods were required. These types of concerns were also factors in cessation or modifications of operations at some similar overseas sites (Payne, 2015).
- A perceived need for improved monitoring and characterisation of the site.
- The possible future change in land-use of the area which rendered the existence of a radioactive waste disposal site more controversial.
- Evolving public expectations of the environmental aspects of AAEC activities and increasing sensitivity surrounding the disposal of radioactive wastes.

These factors undoubtedly contributed to the cessation of disposals at the site.

8. Disposal practices during the operational period

The purpose of this section is to present an overview of the findings of a detailed examination of the available disposal records. The contents of specific trenches may have implications for the remediation of the trenches, for example, potentially making specific trenches (or groups of trenches) a higher remediation priority, or requiring specific management or safety precautions.

The number of trenches filled annually and the volume of wastes disposed appears to have been relatively constant during the disposal years at LFBG (between 7 and 10 trenches were filled per calendar year). However, the amounts of activity disposed annually were not constant, being much greater during the final two years of disposals (Payne, 2012). This is attributable (at least in part) to emptying out the burial ground store (BGS), where high activity items had been stored whilst they decayed. However, this increase in disposed activity only occurred for the shorter lived Group II and Group III radionuclides. The available records do not suggest the same was true of plutonium (Figure 48).

The following sections provide some observations on the changes in disposal practices during the operational years. Summary information on the trench disposals is given in Appendices B to F.

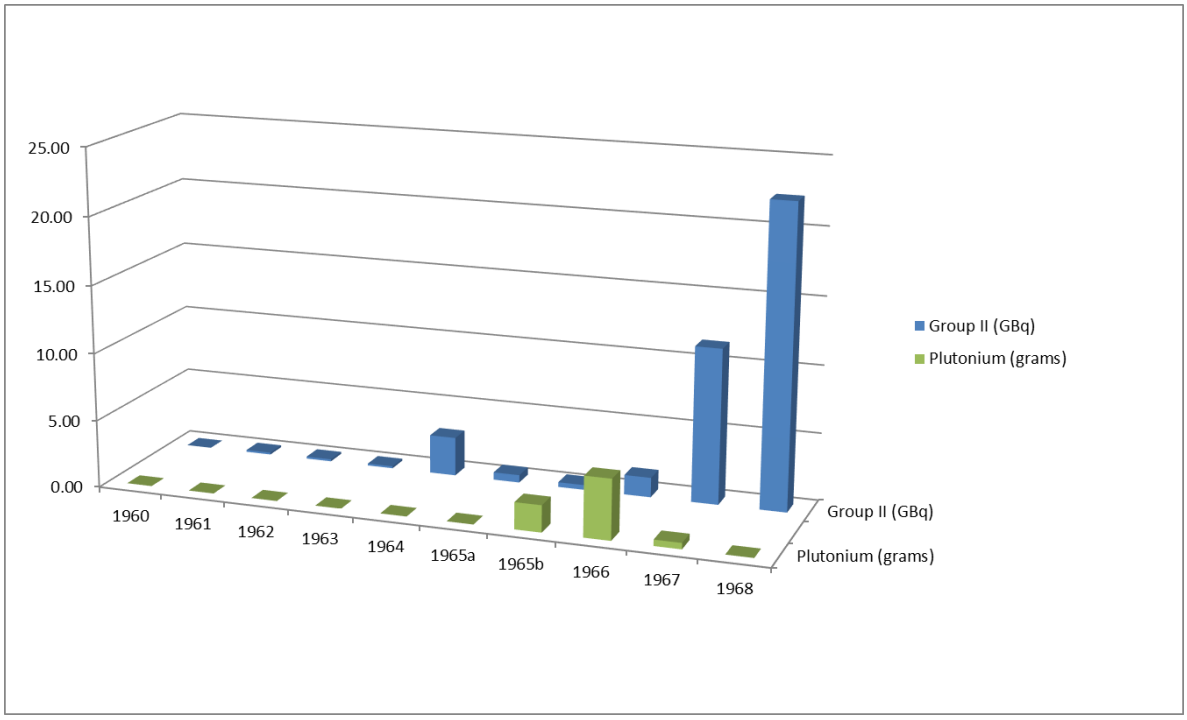


Figure 48. Disposal of Plutonium and Group II radionuclides, showing a large increase in the latter group during the final disposal years. The disposals of Pu do not show this trend.

8.1. Disposals during 1960 (Trenches 1 to 5)

The information on the first 5 trenches is very limited, and comprises a few scraps of paper[21], with a description such as “FB drums and waste” and “negligible activity” (see Figure 19). The precise date of burial was not recorded. Items described as “ducting and filters” were disposed (Section 5.1.1) in either Trench 3 (according to a paper record) or Trench 4 (indicated in the EHM summary). Four sludge drums were disposed in Trench 5. These are the only sludge drums thought to have been disposed before 1964 (Figure 26). It appears that Trench 6 was partially filled on 15 December 1960 and more wastes were added on 6 January 1961.

8.2. Disposals during 1961 (Trenches 6 to 18)

A significant development at the start of 1961 was the reporting of waste disposals in the first Waste Burial Book (WBB). These books are described in Section 3.3.2. Various disposal information was recorded, for example, the categorisations of wastes (LS, LSB, etc.), date of generation, and types of containers. Most wastes disposed in 1961 were either LS or LSB items. Trench 7 was the first trench to have liquids disposed, with three items in the category of LLB (30 gallons of waste oil). No other liquid wastes were known to have been disposed by burial in 1961 (although numerous liquids were burned). Most of the items buried in 1961 were only briefly stored before disposal, possibly even being directly transferred from their laboratory of origin to the waste site. There is no evidence of decay storage having taken place.

Trench 12 was the first trench for which “fertile content” was reported in the EHM summary and the WBR. Investigations undertaken during the current project (see Section 5.4.4) show that the fertile U and Th content was compiled from the SDRs (scrap disposal reports). As shown in Appendix F, the Th content in this trench was derived from SDR 2 (0.9 Kg of Th metal turnings, mixed with rubber in paraffin). The U was from SDR 3, comprising U metal powder (0.3 Kg) mixed with graphite. The items in SDR 4 and SDR 5 (disposed in Trench 14) comprised Th metal powder in coke and pitch. Trench 18 may have contained U-235 items (totalling 5.3 g) although this U-235 consignment appears most likely to have been disposed the following year in Trench 26 (see Section 5.2). Trench 12 contained a bulky item, described as “30 filters”. Some bulky “wooden” items (possibly furniture) were disposed into Trench 14.

Very few pink cards remain for items disposed in 1961 (this also applies for subsequent years until 1965 – see Appendix B). There is a small set of pink cards relating to liquid waste burned in a location reported as “Trench 13” on 4 July 1961. Trench 13 is not marked on any site plans. The EHM summary document gave a volume of 313 ½ gallons (1187 litres) for these items. This considerably exceeds the volume of the wastes reported on the 5 available pink cards (totalling 160 Litres), indicating that some cards have probably been lost. The wastes may have been burned within Trench 14 prior to its filling, in the small feature indicated on the trench map between Trenches 12 and 14 (Figure 2), or elsewhere on the site. The burnt wastes consisted of a variety of organic liquids and solvents.

In total, the records for 1961 indicate relatively small amounts of activity (compared to later years), of radionuclides in Group II and Group III (the less hazardous categories). The reporting of Group I disposals in Trench 10 has been confused, because some records indicate the presence of Group I activity (e.g. the EHM document: Appendix E). However, this apparently arose from a typographical error during the preparation of the EHM. The WBR source document, which was used to compile the EHM, clearly shows the absence of Group I in this trench (Figure 49). However, this is not conclusive evidence of the absence of Group I radionuclides, because the WBR records were incomplete. According to the WBR records, there were no items containing Group I radionuclides disposed at LFBG until 1968[22].

[21] The lack of information on these trenches can be demonstrated by a survey of Appendices B to F

[22] This absence of Group I items was actually erroneous due to failure to account for the group I content of the sludges (Section 6.2), as well as omitting the Group I radionuclides derived from the SDR items (Section 5.4.4).

AUSTRALIAN ATOMIC ENERGY COMMISSION

RESEARCH ESTABLISHMENT, LUCAS HEIGHTS

WASTE BURIAL RECORD — LITTLE FOREST BURIAL GROUND

TRENCH No. 10 — LOCATION — DATE FILLED 11-5-61

WASTE CATEGORY	WASTE COMPOSITION	ESTIMATED ACTIVITY mCi			FISSILE CONTENT gms			FERTILE CONTENT kgms		Be Content kgms	VOLUME CU. FT.
		Group 1	Group 11	Group 111	Pu	U3	U5	U	Th		
LOW LEVEL	Normal Waste	Negligible			Contamination			Present			298·5
MEDIUM LEVEL	Normal Waste		1·0	1·1						10·4	299·0
HIGH LEVEL (DECAYED)	Nil										
HIGH LEVEL (APPROVED BY S.A.C. No.)	Nil										
	TOTALS		1·0	1·1						10·4	597·5

R A Bowtell (Waste Operations Officer)
20/8/68

Figure 49. WBR for Trench 10. There is no entry for Group I radionuclides.

8.3. Disposals during 1962 (Trenches 19 to 26)

The types of wastes disposed in 1962 were generally similar to the previous year (mostly LS and LSB). However, Trench 26, filled just before Christmas 1962, contained far more activity than any previous trench. Some items had been stored for nearly two years, which may indicate the disposal of higher activity items following decay storage. Trench 26 was filled only a few days after Trench 25, and it is possible that higher level items were reserved for separate disposal in Trench 26. Furthermore, the vast majority of the waste in this trench consisted of “Medium level” rather than “Low level” items, including substantial amounts of Be.

Trench 26 also contained a number of U-235 items (documented by SDRs). Some of these were originally thought to have been disposed in Trenches 18 and 19, but extensive cross-checking of the disposal records showed that the U-235 items previously attributed to Trenches 18 and 19 were likely disposed in Trench 26 (Table 3). This would mean that Trench 26 contains (by a considerable margin) the greatest amount of U-235 of any trench at LFLS. Despite some uncertainty about the fate of specific items, it is clear that a significant quantity of U-235 was disposed in Trench 26.

The total amount of liquid waste disposed during 1962 was over 2000 litres, an amount only exceeded in one other year (1966). As well as waste containers placed into trenches, there may have been some additional liquids disposed on 31 March 1962 at an unknown location (described as “MTH” in the WBB). Subsequently, 11 liquid items (totalling 307 litres) were disposed in Trench 21 (in categories of LL and LLB). The EHM summary notes that 72 gallons of organic solvent was disposed in Trench 23. During our investigations, we located a set of 5 pink cards from liquid wastes (indicated as disposed on 4 Oct 1962). This date is between the disposals in Trench 23 and Trench 24. These items may have been poured into a completed trench or burned.

A few large sized items were disposed during 1962, such as a large LSB item of 30 cubic feet wrapped in polythene (Trench 25). One item, a 44-gallon drum from UNSW was entered in the waste burial book then crossed out.

8.4. Disposals during 1963 (Trenches 27 to 36)

Trenches filled in 1963 generally contained numerous items of LS and LSB with a few liquid items, with little reported activity. Most items appeared to be routine wastes, and were disposed shortly after being collected from the source laboratories. A few items had been stored since 1961, and presumably had higher initial contact doses. Some wastes originated from labs which later generated Pu-contaminated items (see Section 7.4).

The first documented disposal of tritium at LFLS was in Trench 28, described as "vacuum oil containing FP and H_3" (i.e. fission products and tritium), and originating from HIFAR. A large consignment of two trailer loads of waste (13.5 cubic metres) was disposed in Trench 30. Individual large items, possibly glove boxes, were disposed in other trenches. Trench 34 included two waste drums from UNSW.

According to WBR 35, Trench 35 contained a "glove box with furnace" and the EHM recorded a "pusher furnace" being disposed in Trench 36. Trench 36 was the last trench filled in 1963, reportedly on December 21st (which in 1963 fell on a Saturday). There may have been some urgency to complete the disposals before the holiday break.

8.5. Disposals during 1964 (Trenches 37 to 46)

There were a number of significant developments in waste disposal practices during 1964, which can be inferred from the disposal records. These included:

- the commencement of sludge burials
- a large number of burnt items (many of which were poorly documented and not included in the itemisations of individual trenches)
- the disposal of some "Tritium Hazard" items
- the disposal of a number of items classed as "high level" (according to the classifications then in use).

Collectively, these changes indicate that disposals at the site had entered a new phase during 1964. They are discussed in more detail in the following sections.

8.5.1. Commencement of sludge drum disposals

The summary record (e.g. Figure 48) shows that the amount of Group II and Group III activity disposed in 1964 was much greater than previous years (by a factor of about 10). The main reason for this was commencement of the disposal of sludges. For all the trenches containing sludge drums, the estimated activity from the sludges exceeded that of the other items.

Trench 39 contained the first set of sludge-containing drums (29 drums). It is perhaps surprising that this disposal occurred, given the findings in an AAEC report from the same year (Bonhote, 1964). This report had suggested that burial of the sludge drums was not a preferred option. However, the drums had reportedly been in a poor condition and may have been in danger of disintegrating. The solidified sludge was noted on a single line in the WBB and allocated a total activity of 14.5 mCi (i.e. 0.5 mCi / drum). This corresponds to a reported total of 536.5 MBq, which was equally split between Group II and Group III radionuclides (thereby overlooking any possible content of Group I radionuclides in the sludges). The sludge accounted for almost all the activity allocated to this trench. Because of the activity allocated to these sludge items, the activity disposed in Trench 39 exceeded all previous trenches. Following the commencement of disposals of the backlog of sludge drums, disposals of sludge drums continued in every trench from Trench 39 to Trench 44.

Trench 41 contained 77 drums of solidified sludge. As the volume of each drum is 0.2 m^3, the total volume taken up by the drums (~ 15 m^3) was a significant proportion of the total waste in the trench (around 19 m^3). The number of sludge drums in Trench 41 was higher than all other trenches except Trench 76 (which was the final trench filled). As with the nearby trenches, the activity of the sludges made a significant contribution to the activity of Group II and Group III radionuclides. Once again, the total activity reported in Trench 41 was greater than any earlier trenches.

The total number of sludge drums disposed in trenches 39-44 was 288 drums (Appendix D), which is slightly greater than the number of drums reportedly present at the burial ground in June 1964 ((Bonhote, 1964)). However, Trenches 45 and 46 did not contain any sludge drums. It appears that, by this time, the backlog of drums had been addressed and relatively few sludge drums were disposed in the following 12 months.

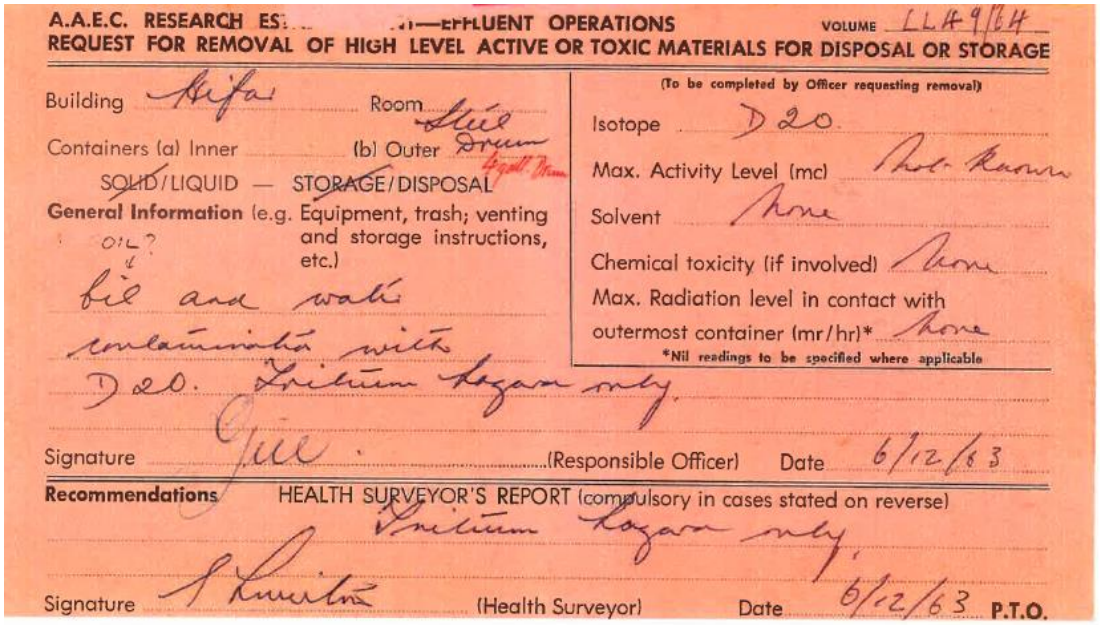
8.5.2. Waste burnings in 1964

Several weeks after Trench 39 was filled, a number of items were recorded in the WBB as having been "burned in a pit at the burial ground". This occurred on two dates (26 and 28 May 1964). These items, totalling over 100 gallons, do not appear in the EHM summary document. The items burned on 26 May 1964 included 55 litres of uranyl nitrate in organic solvent containing 5.3 g of U-235.

Similar incidents occurred on 31 August 1964 and 4 September 1964. A total of over 160 gallons of liquids were burned on these two occasions. As with previous burnings, the details were omitted from the available summary documents, such as EHM and WBR (the latter being organised by trenches and omitting burnt items). The items consisted of waste oil (from both machinery and vacuum pumps), and some significant quantities of waste solvents (some from decontamination of manipulators). One item contained 10 gallons of mixed solvents (toluene, ethanol, and benzene). Radionuclides present included fission products, Th, U_{nat}, and C-14. A number of items reportedly contained Turco^{TM} solvent (the specific solvent composition is unknown).

8.5.3. Disposal of tritium hazard item

A tritium contaminated item in Trench 46 (described as a "Tritium Hazard" and originating from the HIFAR reactor) was the first disposed item which is known to have contained hazardous levels of tritium (Figure 50), although it is possible that similar items were disposed previously. The disposal of tritium contaminated items at LFLS has not previously been conclusively demonstrated, despite the existence of a tritium plume and indirect evidence (such as the presence of tritium in the HIFAR reactor). Trench 46 is towards the northern end of the eastern set of trenches, where a tritium plume has been detected.



A.A.E.C. RESEARCH ES... ...t—EFFLUENT OPERATIONS VOLUME LL#9/64

REQUEST FOR REMOVAL OF HIGH LEVEL ACTIVE OR TOXIC MATERIALS FOR DISPOSAL OR STORAGE

Building Hifar Room Cell

Containers (a) Inner (b) Outer Drum Light Mtm

SOLID/LIQUID — STORAGE/DISPOSAL

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

oil?

oil and water contaminated with D20. Tritium Hazard only.

(To be completed by Officer requesting removal)

Isotope D20

Max. Activity Level (mc) Not known

Solvent None

Chemical toxicity (if involved) None

Max. Radiation level in contact with outermost container (mr/hr)* None

*Nil readings to be specified where applicable

Signature ... (Responsible Officer) Date 6/12/63

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

Tritium Hazard only.

Signature (Health Surveyor) Date 6/12/63 P.T.O.

Figure 50. Disposal of a tritium hazard item (LL49/64) in Trench 46.

8.5.4. Other significant items disposed in 1964

Trench 39 contained the first disposed item known to have been categorised as “High Level” (Appendix C). It originated in 1961 from room B2-167, a laboratory where plutonium was handled (Section 7.4). Later in 1964, a further five HL items were disposed in Trench 45 (decay-stored since 1960 and 1961).

Trench 38 contained 13 empty sludge drums from the treatment plant (each 44 gallons) and 10 drums (44 gallons each) of “uranium ore” from UNSW which had been stored since 1961. The amount of uranium ore was later estimated as being approximately 3 tonnes. Based on the reported activity, the ore-grade was relatively low and in total contained less than 1 Kg of uranium. This trench also contained two liquid items stored since 1960, and an item consisting of about 300 mL of organic liquid (containing 1.2 g of U-235). Trench 41 contained much greater amounts of U-235 than most other trenches (16.22 g) disposed as a single item described as “machining sludge” (SDR 25). According to WBR 41, a filter unit was disposed in this trench. Trench 45 apparently contained a cutting / grinding machine (originating from Building 16) which had a volume of 46 cubic feet. The source of the 3.8 Kg of Uranium in Trench 45 was the disposal of various items listed in SDR 27 (Appendix F).

While numerous items were incinerated in 1964, there was also a substantial number of liquid-filled containers disposed into the trenches. The inventory of liquids in Trench 34 showed that some of these would not have been flammable, comprising water-based liquids containing various contaminants.

Trench 46 is the first trench reported in the third waste burial book (WBB-3) and also the first trench for which an almost complete set of liquid wastes (LL/LLB) pink cards exists. According to the WBR and the EHM summary, this trench had very little activity disposed in it. However, the pink cards reported “glove-box washings”, which may have contained Pu. The descriptions of these items resemble known Pu-contaminated items (SDR 34 and 35), which were described as “glove box cleanings” and were buried in Trench 55 (see Figure 15 and Appendix F). Various other items originated from laboratories which were handling plutonium.

8.6. Disposals during 1965 (Part 1 - Trenches 47 to 51)

Disposals in 1965 commenced with Trench 47, which is towards the north-eastern edge of the trenched area. Subsequent trenches were each a few metres further north. When Trench 51 was filled in October 1965, the operations had reached the northern extremity of the first main block of trenches. It is not known why the disposals were moved to another part of the site. The following two trenches (52 and 53) were filled in late December 1965, in a new block to the west of the first set of trenches (Figure 2). Thus, the eastern end of Trench 52 and the western end of Trench 1 are in close proximity. Some significant aspects of the contents of Trenches 47 to 51 are summarised in the following sections.

8.6.1. First recorded U-233 disposals

Trench 47 was the first trench filled in 1965, and is also the first trench known to have contained U-233. The buried items reportedly contained 1.17 g of U-233, derived from the items in SDR 29. The summary lists of items disposed in trenches (Appendix E) and of the SDRs (Appendix F) both confirm the disposal of U-233 in Trench 47 and/or Trench 48, although they are slightly inconsistent. This is probably because of the splitting of the items in SDR 29 between these two trenches. It seems likely that some U-233 may have been buried in earlier trenches, however the absence of any pink cards for trenches before trench 50 (other than a few liquids) means there is no solid evidence of this. The U-233 items were described as “absorbent tissues impregnated with the oxide” and apparently 100 lead bricks were also included in this waste consignment.

8.6.2. Increased Th-232 disposals

Although there had been previous reported disposals of Th-232 (in trenches 12 and 14), the disposals of 4 Kg of Thorium in Trench 48 and then 14.6 Kg in Trench 51 were much greater than previously reported. The final trench on the northern end (Trench 51) contained the largest single known disposal of Th-232 at LFLS (14 .6 Kg).

8.6.3. The first preserved sets of pink waste cards

Trench 50 is the first trench for which a significant number of pink cards have survived (for 138 of the 785 known disposed items). A few pink cards indicated the presence of Pu, Th, and U-235 (6.04 g, also reported in SDR 37). However, only U-235 was mentioned in the summary EHM document (which was based only on the SDRs). It is possible that the pink cards for the earlier trenches (if available) would also indicate the presence of some actinide contamination. Some of the other key items in Trench 50 included a package of D_2O swabs (which lacked activity information), items from a beryllium lab, and some other isotopes which had not been previously reported.

8.6.4. Other significant items disposed in Trenches 47 to 51

Disposals during 1965 in the northern end of the first trenched area (Trenches 47 to 51) included:

- 40 empty sludge drums (Trench 47), together with 50 cubic feet of filters
- 49 filled sludge drums (Trench 49)
- U-235 (8.9 g), and 130 gallons of Zinc Bromide (Trench 50)
- The solvent Tri Butyl Phosphate (TBP) (Trench 50), which has the potential to mobilise actinides and has been detected in recent groundwater samples from LFLS (Rowling et al., 2017).
- 3 glove boxes (Trench 51) which may have been contaminated.

8.7. Disposals during 1965 (Part 2 - Trenches 52 and 53)

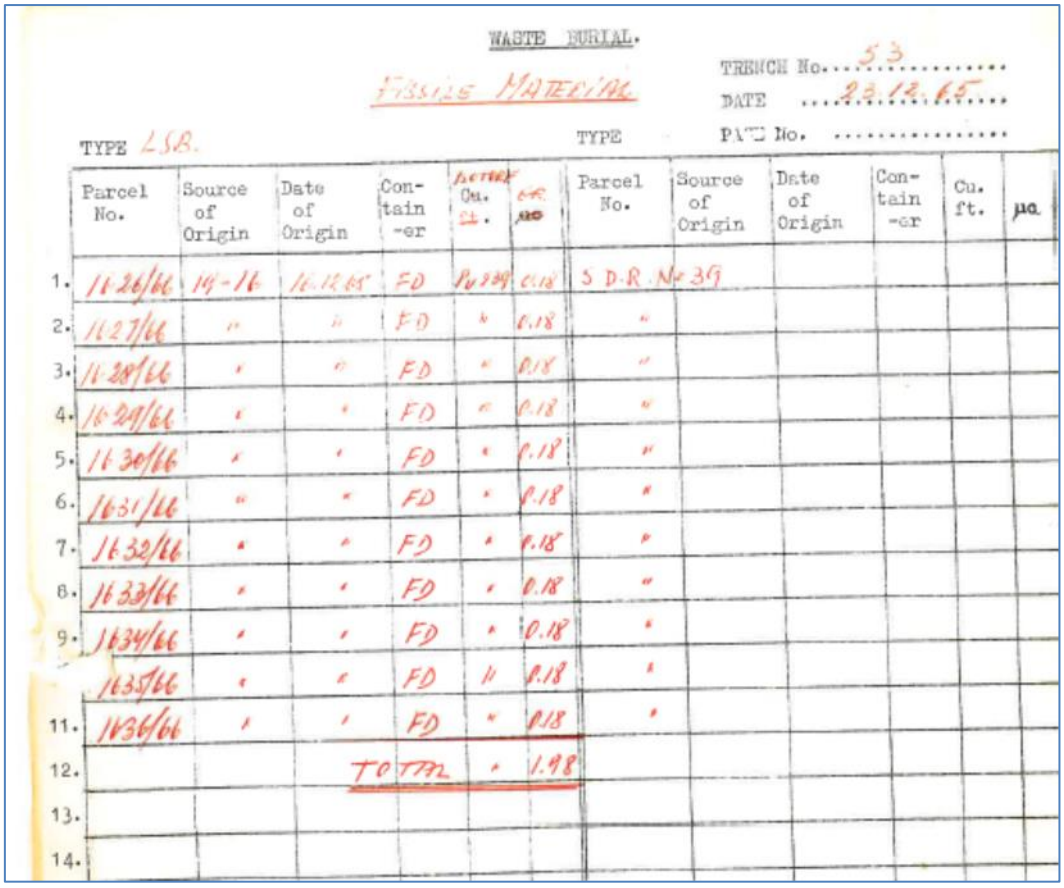
Following the filling of Trench 51 in mid-October 1965 there was a delay of 2 months, after which Trench 52 was filled on 14 Dec 1965. Trench 52 was the first of the western trenches filled (therefore is the most southerly trench in this set). A set of 85 pink cards (all for LSB items) exists for Trench 52, covering about 10% of the 822 items disposed in this trench. Some cards reported the presence of traces of Pu and U-233, and several originated from B2 rooms 166 and 167 (in which work involving actinides took place: see section 7.4).

8.7.1. Disposal of Plutonium in Trench 53

The commencement of disposals of gram quantities of plutonium at Little Forest (in Trench 53) is one of the most significant developments in the disposal operations at LFBG. The waste was described as “glove box cleanings” (similar to the items reported in Figure 15). Following this incident, a new summary page was filled out in the WBB, which had transitioned to a loose-leaf form (Figure 11). The summary page showed the Pu items in red ink (Figure 51), with details including the SDR report (SDR 39), the laboratory of origin, as well as the dates of generation and disposal.

No Group I activity was reported for this trench in the original summary inventory (in either the WBR or EHM). However, 1.98 g of Plutonium, which is a Group I radionuclide, has an activity of about 5.5 GBq (Table 5) [23]. The significant amount of Pu in this trench (which is greater than any of the other trenches apart from Trench 55) makes a substantial, previously overlooked, contribution to its Group I activity and to the site inventory of Group I radionuclides. The listed Pu items (Figure 51) were disposed just 7 days after their “date of origin” (reportedly 16 December, 1965), on the day before Christmas Eve, 1965. It is possible that the proximity of the festive season created some urgency for the disposals to be undertaken in a short time-frame. It is also noted that the conditions for the criticality certificate for LFBG were modified on 21 December 1965 (Figure 41), which may have been related to the disposal of these specific items.

[23] This calculation is based on the disposed Pu being a combination of Pu-239 (~92%) and Pu-240 (~8%) which can be deduced from environmental measurements (Section 5.4.4). Both of these isotopes are alpha-emitters, although the probable presence of Pu-241 (which was not mentioned in the disposal records) means that there would have been an additional component of beta-activity. According to the IAEA classifications (Section 5.4.1) Pu-241 would be classified as a Group I radionuclide. Note that Pu-241 has a much shorter half -life than Pu-239 and Pu-240.



WASTE BURIAL.

FISSILE MATERIAL

TRENCH No. 53

DATE 23.12.65

TYPE LSB.

TYPE

P.V.C. No.

	Parcel No.	Source of Origin	Date of Origin	Con-tain-er	Cu. ft.	µg	Parcel No.	Source of Origin	Date of Origin	Con-tain-er	Cu. ft.	µg
1.	1626/66	14-16	16.12.65	FD	Pu239	0.18	S.D.R. No 39					
2.	1627/66	"	"	FD	"	0.18	"					
3.	1628/66	"	"	FD	"	0.18	"					
4.	1629/66	"	"	FD	"	0.18	"					
5.	1630/66	"	"	FD	"	0.18	"					
6.	1631/66	"	"	FD	"	0.18	"					
7.	1632/66	"	"	FD	"	0.18	"					
8.	1633/66	"	"	FD	"	0.18	"					
9.	1634/66	"	"	FD	"	0.18	"					
	1635/66	"	"	FD	"	0.18	"					
11.	1636/66	"	"	FD	"	0.18	"					
12.			TOTAL			1.98						
13.												
14.												

Figure 51. The summary page reporting the disposal of Pu in Trench 53.

8.8. Disposals during 1966 (Trenches 54 to 61)

The available information suggests that there were further significant developments in disposal practices during 1966, as discussed in the following sections.

8.8.1. The largest recorded disposal of Pu

Trench 55 contained the single largest disposal (SDR 35) of plutonium (3.7 g) at the LFLS (Figure 15) and additional Pu (0.72 g) from SDR 34. There were also disposals of U-233 and U-235 (documented in SDRs 40, 41 and 43) in Trench 55. This combination of significant amounts of several fissile isotopes was not repeated in any other trench. Many other disposed items contained stated or potential actinide contamination.

There are some notable aspects of the disposals of Pu in Trench 55 including:

- The Pu in items SDRs 34 and 35 amount to a total of 4.42 g, which contributed 12.3 GBq of Group I activity. Thus, this single trench contains more than 10 times as much Group I activity than appeared in the entire inventory for the LFBG site (as tabulated in the EHM document).
- The Pu content disposed in Trench 55 was considerably higher than the definition of both Low- and Medium-level waste defined under either the then-existing or subsequent (more relaxed) standards proposed in SAP/P5. According to the definition of medium level waste in SAP/P5, no more than 10 mg Pu-239 should have been disposed in a single package (Section 7.2). Whether defined by activity or by mass of Pu, the amount of Pu disposed in this trench was more than 2 orders of magnitude higher than the definition of “medium level” waste.

8.8.2. Large volumes of liquids

Large amounts of liquid were disposed during 1966, totalling nearly 3000 litres. A major proportion (~1800 litres) was disposed in Trench 55, which (as discussed above) also contained the largest known source of Pu in any trench at the site. This was a problematic combination, and as a result, this trench could constitute a potential source of Pu in mobile forms (as was later recognised – see Figure 60). The records indicate the disposal of another batch of liquids about a month after the trench was filled. It is not clear if these liquids were poured in on top of the filled trench, or the trench stayed open for a long time, or this was simply a reporting error (in the date) when filling out the page. There is also evidence that liquid wastes were also added to Trench 61, approximately one month after the solid disposals in that trench took place.

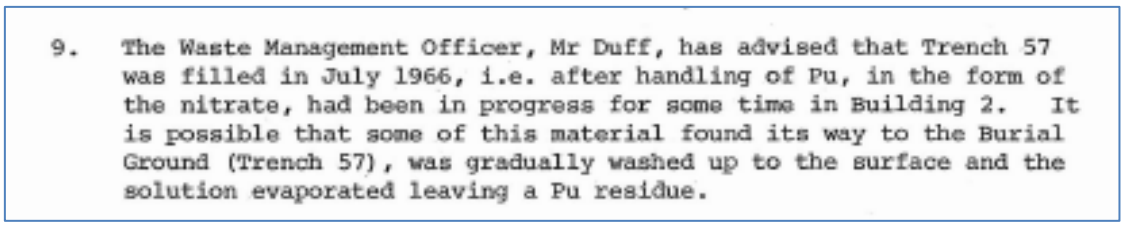
8.8.3. Disposal of enriched uranium

Trench 58 contained 4.45 g of uranium, enriched to 93% U-235 (described on SDR 46), containing 4.14 g of U-235. This was described as “co-precipitated material… in the form of powders and sintered particles”, within a sisal disposal drum.

8.8.4. Other actinide disposals

There appear to have been increasing amounts of actinide contaminated items (other than SDR items) disposed during 1966. For example, a summary sheet for Trench 55 mentioned 69 mg of Pu from non-SDR items, and similar entries appeared on some other summary sheets (usually reported in red-ink, as in Figure 51). The actinide summary report for Trench 58 included Th-232 (19 g), as well as the 4.14 grams of U-235 (mentioned above). Five Pu items were also listed but the amount of Pu was unspecified. During 1966, a new waste category (“F”) indicating “fissile” materials was added. Only a few disposed items were in this category (Appendix C), however these items may well have contributed additional Pu (or other actinides) to the reported inventory.

Later environmental monitoring revealed the presence of plutonium near the trenches filled in 1966, and it was speculated that unreported disposals may have occurred in Trench 57 (Figure 52). It was even considered possible that Pu of “Maralinga origin” was disposed at LFBG (Figure 61) although there is no solid evidence to support this suggestion.



9. The Waste Management Officer, Mr Duff, has advised that Trench 57 was filled in July 1966, i.e. after handling of Pu, in the form of the nitrate, had been in progress for some time in Building 2. It is possible that some of this material found its way to the Burial Ground (Trench 57), was gradually washed up to the surface and the solution evaporated leaving a Pu residue.

Figure 52. A suggestion that Trench 57 may have contained more plutonium than reported, based on environmental sampling in the 1980s (from minute paper dated 28 January 1983).

8.8.5. Other comments on 1966 disposals

Other specific items disposed in 1966 included some hospital-derived waste, placed in Trench 56. Trench 58 included two drums of liquid waste from UNSW and at least 7 other waste packages from that source. Another development was that, for the first time, the sludge drums placed into the final trench filled in 1966 (Trench 61) were each assigned a LSB number and an individual nominal activity.

8.9. Disposals during 1967 (Trenches 62 to 70 and Trench S1)

The second last year of disposals at LFBG was 1967, during which the amount of disposed activity rapidly increased. Numerous pink cards are available, providing information on the types of items which were disposed. Some of the notable features of disposals during 1967 are mentioned in the following sections.

8.9.1. Disposal of U-233 and other actinides

The U-233 disposed in Trench 67 (2.5 g) was the greatest amount of this isotope reported of any trench and amounted to nearly 50% of the total reported LFLS inventory of this isotope. It comprised the U-233 content reported in three SDRs (SDR 72, 79 and 80). Numerous packages were reported to contain Pu-239, U-233 and other actinides. Some of the Pu items were sourced from cleaning Pu gloveboxes. Several items contained U-233 dissolved in solvents (either TBP or DSBPP - di-sec-butyl-phenyl-phosphonate). One item contained Am-241 and (unusually) Cm-244 as well as Pu-239.

8.9.2. Further consideration of sludge activities

There were further developments in the accounting of the sludges during 1967. For the first time, activities for individual drums were included (rather than a single estimate for all drums). For example, the sludge drums in Trench 64 were assigned activities (ranging from 0.601 mCi to 7.12 mCi), although it is not known how these were determined. In many trenches, the sludge drums made a significant contribution to the activity disposed. However, the activity of the sludges was arbitrarily allocated between Groups II and III and there was still no recognition of the possible Group I activity, which was only taken into account in the final year of disposals (1968).

8.9.3. Disposal of higher activity items

Another significant development in 1967 was an acceleration in the amounts of activities disposed, which considerably exceeded any preceding year. This increase reflected the changes to the disposal requirements. Until the SAP/P5 document was approved on 26 July 1967, all waste buried was classified as low level and had a dose rate less than 5 mR/hr. The adoption of the proposals in SAP/P5 (Bonhote, 1967) made possible the disposal of items with surface dose-rates of up to 200 mR / hr.

Following the relaxation of disposal limits, increasing amounts of decay-stored items (which nevertheless had relatively high residual dose-rates) were buried. For example, Trench 66 contained numerous items stored (presumably in the BGS) since as early as May 1962. As a result of the high activity of these items, the inventory of both Group II and Group III in this trench was much greater than in any previous trench. The subsequent trenches from 68 onwards contained the vast majority of all activity disposed at the site (Appendix E).

8.9.4. Disposal of “Ragged ends”, tritium-contaminated items, and other HIFAR wastes

A new waste stream documented in 1967 was “Ragged Ends”, which were obtained by cutting the ends off HIFAR fuel rods (Figure 53). They did not include the actual fuel elements. The ragged ends were usually reported as containing “MFPs” (mixed fission products) and were relatively active. One trench contained approximately 25 ragged ends from HIFAR, which had been decay-stored (in some cases since 1961), but nevertheless had high residual dose rates (as high as 190 mR/hr). Other cards reported “active corrosion products from HIFAR” and discarded piping from the active drain to the delay tanks. Other wastes included:

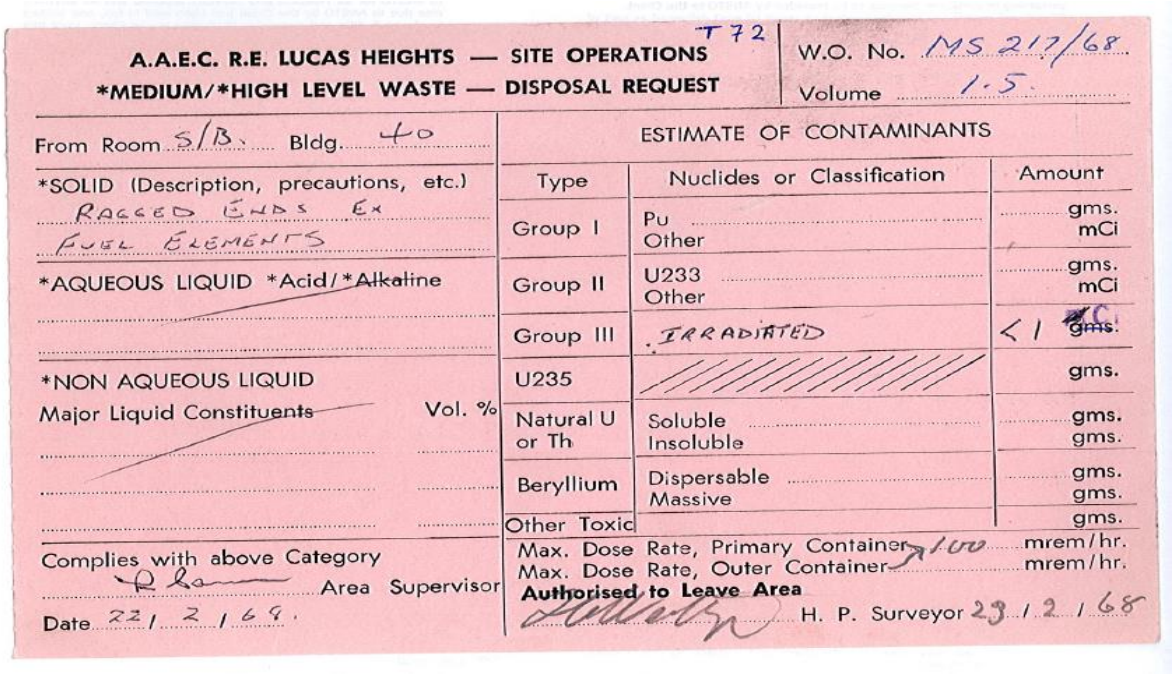
- Multiple flux scanning wires which had been used in HIFAR
- Swarf from cropping fuel elements
- Aluminium cans from hot cells, sometimes described as “Harwell-type” cans, which had been irradiated in the reactor. The radionuclide content was often indicated as U, Th, and MFP.
- Active-area vacuum cleaner bags, including from hot cells.

Numerous items were contaminated with tritium, including:

- D_2O swabs from HIFAR (4 batches)

- Wastes from D_2O pumps.
- Tritium in mixed organic solvents
- Discs from D_2O lines
- Waste from HIFAR pipes and red area sinks.

Thus, the trenches filled in 1967 are likely to contain major sources of tritium.



T 72

A.A.E.C. R.E. LUCAS HEIGHTS — SITE OPERATIONS
*MEDIUM/*HIGH LEVEL WASTE — DISPOSAL REQUEST

W.O. No. MS 217/68
Volume 1.5

From Room S/B. Bldg. 40

*SOLID (Description, precautions, etc.)
RAGGED ENDS EX FUEL ELEMENTS

*AQUEOUS LIQUID *Acid/*~~Alkaline~~

*NON AQUEOUS LIQUID
Major Liquid Constituents Vol. %

Complies with above Category
Area Supervisor
Date 22/2/69.

ESTIMATE OF CONTAMINANTS

Type	Nuclides or Classification	Amount
Group I	Pu	gms.
	Other	mCi
Group II	U233	gms.
	Other	mCi
Group III	IRRADIATED	< 1 ~~gms.~~
U235		gms.
Natural U or Th	Soluble	gms.
	Insoluble	gms.
Beryllium	Dispersable	gms.
	Massive	gms.
Other Toxic		gms.

Max. Dose Rate, Primary Container 100 mrem/hr.
Max. Dose Rate, Outer Container mrem/hr.
Authorised to Leave Area
H. P. Surveyor 23/2/68

Figure 53. A pink card for "Ragged Ends from fuel elements".

8.9.5. Increased confusion in the record-keeping

Towards the end of 1967, the record-keeping of disposals at LFBG became increasingly fragmentary. Trench 67 was the last trench for which individual items were reported in the WBB. An inventory of items in the Burial Ground Store (recorded in a book referred to as the "BGS book", see section 3.3.3) was made on 17 August 1967, and it is presumed that most of these items were subsequently buried in the trenches. Many of the items listed in the BGS book have been annotated with disposal dates. Thus, the BGS book provides some indication of what was disposed in trenches after the WBB records ceased, and can be compared with the available pink cards. However, items that arrived at the burial ground after August 1967 were not included in the BGS book. For trenches after trench 67, numerous pink cards are available, but they have not been stored in a systematic and orderly fashion. Rather they were bundled together, as shown by the wrapping of the cards for Trench 69 (Figure 54).

The limited information recorded on the paper wrapping is not consistent with the contemporary summary in the corresponding Waste Burial Record (WBR 69). This kind of discrepancy is difficult to resolve. In general, the records for the final 12 months of disposal operations are insufficient to definitively assign waste packages to particular trenches, although the availability of a larger number of pink cards does provide some useful information on the variety of items disposed. The inadequate labelling of the stored pink cards has created additional uncertainty in interpreting the disposal records.

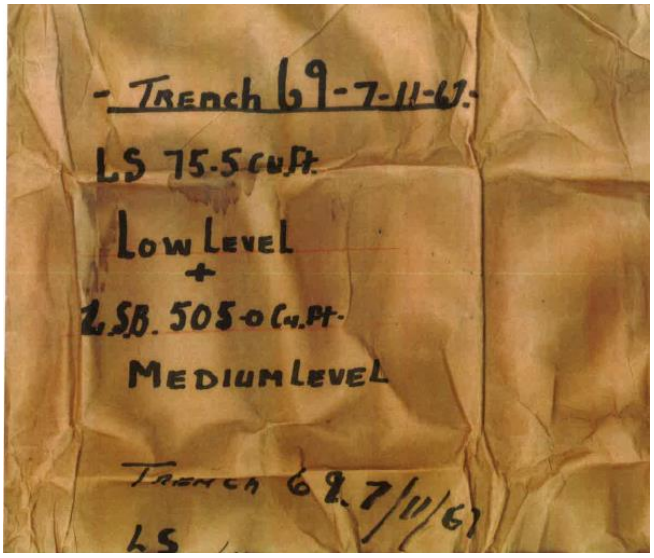


Figure 54. Packaging of Pink cards from Trench 69.

8.9.6. Trench S1

The first 3 trenches completed in 1967 were Trench 62, Trench S1 and Trench 63, which were all reportedly filled in a short period between 14 and 18 March. Trench S1 was located within the fenced area, but to the south of the main trenched areas. It is not known why S1 was separated from the main blocks of trenches (the only nearby trench is S2, constructed in April 1968). Possible reasons may include: segregation of different types of wastes (e.g. on the basis of higher dose-rate, chemicals contained, biohazard, etc.), the disposal of larger objects (S1 may be a wider trench), or proximity to the medium level decay hut. The latter explanation may be supported by burial of a large number of decay-stored items in this trench, with at least 32 items originating between 1960 and 1963. The available evidence (i.e. the WBB) suggests that this trench contained many of the most active items disposed until that time. There is also the possibility of an incident occurring during the filling of Trench 62 requiring a separate, isolated trench to be commissioned. Possibly Trench S1 was separated from the others because there was an operational need for it to be open (being excavated and/or filled) at the same time when Trench 62 was being filled. This may have avoided the safety hazards and logistic complexities of operating multiple trenches in close proximity. However, the information on Trench S1 disposals is sparse, since there are no fissile or SDR records and there are no surviving pink cards for this trench.

8.9.7. Summary of pink card record for 1967

The number of pink cards available for 1967 considerably exceeds any previous year. These cards give valuable insights into the variety of objects which were disposed in that period (many of these were discussed in preceding sections). It is not known how representative the surviving cards are of the contents of earlier trenches. It appears likely that, given the acceleration of more active disposals in 1967, they may represent more active items than those disposed in earlier years.

The pink cards document a variety of items in addition to those mentioned above:

- Various contaminated liquids and sludges, including waste oil, and contaminated stripped paint
- Numerous items apparently originating from early research into medical isotopes (Mo-99, Tc-99) as well as activation products and possibly tracers. These included P-32, Co-60, Cr-51, Au-198, and Cu-64. Many of the shorter-lived isotopes will have since decayed and not represent a long-term hazard. However, their presence reflects a broadening range of activities by the AAEC.

- Several items containing large amounts of beryllium, in some cases described as “beryllium salts”.
- Many miscellaneous laboratory items such as damaged glass dessicators, tweezers, scoops, brushes, pill packs, chains, can openers, hypodermic syringes (with reported contents including Co-60, Sr-90, and Cs-137) and discarded isotope bottles in lead pots.

8.10. Disposals during 1968 (Trenches 71 to 76 and S2)

The final year of operations (1968) saw another acceleration in the amounts of activity disposed. Not only did the reported activities exceed any previous year in all three categories (Groups I, II and II), but the 1968 disposals accounted for the majority of the activity disposed during the entire operational period. The activity reported in Group I during 1968 (Appendix E) was reportedly 95% of the total disposed at LFBG[24], with the corresponding amounts for Group II and III being 57% and 81% respectively. It is possible that the rate of disposals accelerated when it became known that the site might soon be closed. Trench 71 (filled during 1968) had the greatest reported activity of both Group II and Group III in any trench, and among the highest Group I content. In fact, approximately a third of the reported total activity at LFBG was disposed in this single trench. Various disposed items were described as “high activity”, with very high contact doses corresponding to the allowable limit of 200 mR/hr. Some of these were identified as containing U, Th, MFP, Mo-99, Tc-99, etc. indicating irradiation of samples in the reactor.

Other significant developments during 1968 are summarised in the following sections.

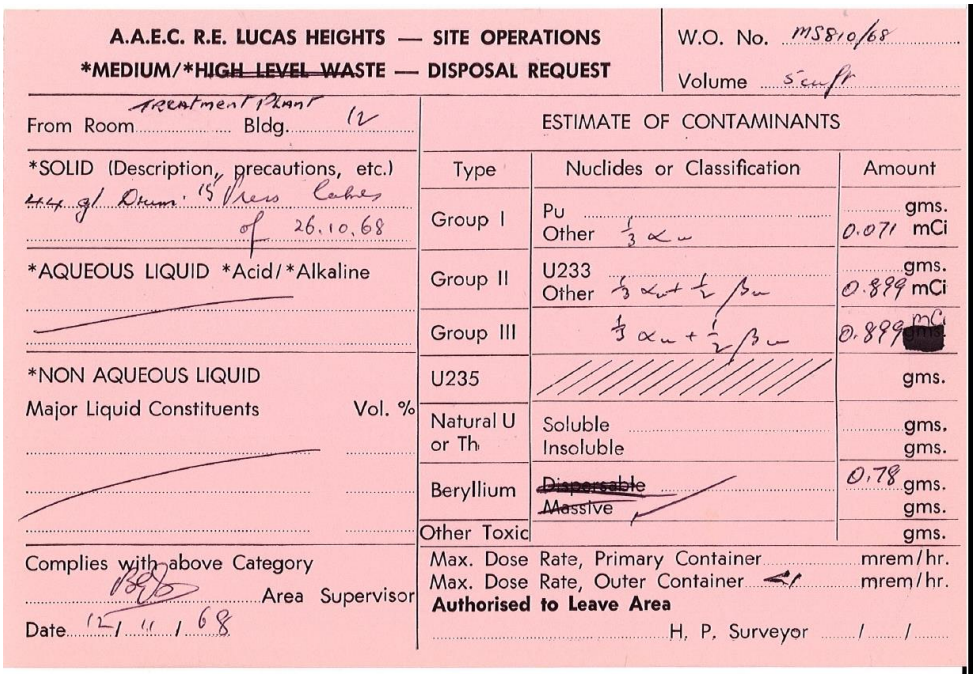
8.10.1. Group I radionuclide content of sludges

The initial trench filled in 1968 (Trench 71) was the first trench at LFBG to be allocated a Group I activity[25], and this was because the Group I content of the sludges was finally taken into account. In all previous trenches, this possibility had been ignored, even though an earlier report had indicated the presence of alpha activity in the sludges (Bonhote, 1964). (Alpha-activity was associated with Group I radionuclides, as discussed below). The presence of Group I activity was subsequently reported in all trenches filled in 1968 (with the exception of S2, which did not contain any sludges). A comparison of pink cards for sludges disposed in Trench 70 and 71 clearly shows the changed method of reporting the radioactive content of the sludges (Figure 32).

The pink cards for sludges disposed during 1968 provide a valuable insight into how the activity content of the sludges was estimated. In earlier years, the Group II and Group III content of the sludges had been assumed to be equal and the Group I content was ignored. However, for sludges disposed in 1968, the alpha-activity of the sludges was apparently individually measured, and one third of this was arbitrarily assumed to be Group I radionuclides (Figure 55). This procedure probably applied throughout 1968, which was the only year for which the Group I content of the sludges was considered. Therefore, the Group I content of just 205 of the 799 sludge drums (those disposed in 1968) was included in the inventory. This oversight is one of the major potential sources of uncertainty in the reported inventory estimates (see Section 6.2). It cannot be known whether the missing radionuclide content of earlier sludges is similar to, greater than, or less than, the reported content of the drums disposed in 1968.

[24] Although this proportion was actually an over-estimate because the Group I activity for most previous years was incorrectly assumed to be zero.

[25] Excluding the transcription error which apparently assigned Group I activity to Trench 10 (Section 8.2).



A.A.E.C. R.E. LUCAS HEIGHTS — SITE OPERATIONS
MEDIUM/~~HIGH LEVEL WASTE~~ — DISPOSAL REQUEST

W.O. No. MS810/68
Volume 5 of 5

From Room Treatment Plant Bldg. 12

*SOLID (Description, precautions, etc.)
44 gl Drum: 15 Ves Cakes of 26.10.68

*AQUEOUS LIQUID *Acid/*Alkaline

*NON AQUEOUS LIQUID
Major Liquid Constituents Vol. %

Complies with above Category
Area Supervisor
Date 12/11/68

ESTIMATE OF CONTAMINANTS

Type	Nuclides or Classification	Amount
Group I	Pu Other $\frac{1}{3}\alpha_u$	gms. 0.071 mCi
Group II	U233 Other $\frac{1}{3}\alpha_{ut}+\frac{1}{2}\beta_u$	gms. 0.899 mCi
Group III	$\frac{1}{3}\alpha_u+\frac{1}{2}\beta_u$	0.899 mCi
U235		gms.
Natural U or Th	Soluble Insoluble	gms. gms.
Beryllium	~~Dispersable~~ ~~Massive~~	0.78 gms. gms.
Other Toxic		gms.

Max. Dose Rate, Primary Container mrem/hr.
Max. Dose Rate, Outer Container <1 mrem/hr.
Authorised to Leave Area
H. P. Surveyor / /

Figure 55. A pink card for treatment plant sludges disposed late in 1968, with the calculation method shown (α activity being evenly split between Groups I, II, and III). This card provides a valuable insight into the reporting method in use at this late stage in disposals at Little Forest.

8.10.2. Disposal of dispersible beryllium in Trench 73

Since the time of disposals, it has been realised that the presence of beryllium at the site is a significant safety consideration and has an impact on the way the site should be managed (AAEC, 1985). As beryllium presents an inhalation hazard, the most hazardous form of beryllium is powdered materials. Numerous items of dispersible beryllium were disposed in Trench 73 (as detailed in Section 7.5). Some were indicated as originating from the BeO sphere manufacturing program. Due to their hazardous nature, these were among the more problematic items buried at the site and required a specific approval by the Safety Assessment Committee (Figure 42).

One curious aspect of the beryllium disposals at LFLS is that the total amounts of Be wastes were apparently much less in the final year of disposals (1968), as shown in Appendix E. There is a possibility that work generating beryllium contamination had been scaled back. However, the disposal of decay-stored LSB items should have ensured that significant amounts of beryllium were still being disposed at this time. The apparent decrease in Be disposed seems most likely to be due to changes in waste categorisation and accounting. Possibly all the LSB items had been disposed of in previous trenches, or alternatively a new waste categorisation had been adopted for the Be contaminated items.

8.10.3. Trench S2

Trench S2 is located to the south of the main trenched area (near Trench S1) and was filled on 8 April 1968, just 3 days after Trench 72. Trench S2 apparently only contained a small number of items from a university, of negligible activity. It is possible that the trench contains other items originating externally from the AAEC site and that the documentation for these other items was not available when the summary document was filled out.

8.10.4. Pink cards for 1968

Similar to 1967, the available Pink Cards for 1968 reflect a diversity of wastes. In general, they resembled the items mentioned for 1967 with a few notable items including:

- A lead (Pb) camera
- Ion exchange column

- Stainless steel flux can plugs from HIFAR
- Highly active contents of vacuum cleaners
- Further ragged ends from HIFAR and flux scan wires.
- Hypodermic needles contaminated with Cs-135, Cs-137, Eu-152, and S-35
- Numerous Co-60 contaminated items (possibly associated with the irradiation facility and/or hot-cell wastes)

8.10.5. Inadequate record keeping

The survey of the available records reveals that disposals tended to more disorganised than previously, with generally poor record keeping. The disposal of 39 sludge drums in Trench 73 was not mentioned in the available summaries. An additional error in the reporting of Trench 75, resulted in a rare case of an over-estimate of Group I activity disposed (see Section 6.3).

8.10.6. Sludge drums in Trench 76

A large number of sludge drums (85) were disposed in this trench. The dimensions of the 44 gallon drums are approximately 572 mm in diameter and 851 mm in height. Thus, the drums would have taken up most of the width of the trench (around 2 feet, 600 mm). The entire length of a 25 m trench would accommodate approximately 44 drums (standing up), or 29 drums (on their sides). A double layer of vertical drums would be around 170 cm high, and a maximum of 88 drums would fit into a 25 m trench. If arranged horizontally, a triple layer stack would be 172 cm high and the trench would accommodate approximately 87 drums. The total volume of 85 drums (200 L each) would amount to 17 cubic metres which is slightly greater than the reported volume of medium level waste in this trench. These considerations show that this trench was likely almost entirely full of drums, with very little room for other waste. It is believed that part of the reason that the sludge drums were disposed was because they had become deteriorated and were unsuitable to take back to the main site (Section 4.3). This fact, coupled with the imminent cessation of disposals (assuming that the operators were aware of this) would have been a strong incentive to dispose of them rather than attempt to return them to the main site.

8.10.7. Trench 77 partially excavated but never filled

The final trench operation undertaken at LFBG was the partial excavation and then re-filling of Trench 77 which did not contain active waste (Figure 56). The site was then cleaned up and no subsequent disposals took place.

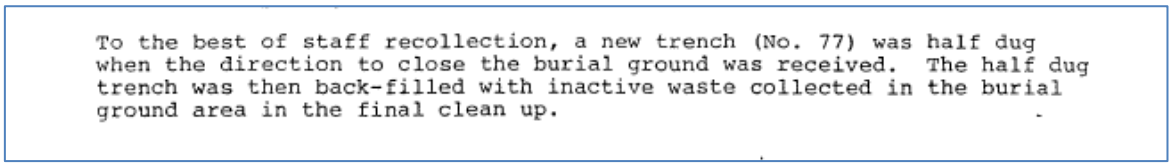

To the best of staff recollection, a new trench (No. 77) was half dug when the direction to close the burial ground was received. The half dug trench was then back-filled with inactive waste collected in the burial ground area in the final clean up.

Figure 56. Information included in the EHM document regarding Trench 77.

9. Physical / Chemical Information

9.1. Physical aspects

There are a number of options for management / remediation of the LFLS, and the effectiveness of these options may be affected by the physical and chemical properties of the wastes. Consequently, the disposal records (specifically the WBBs and the pink cards) were examined to gain more information on the wastes. In general, these aspects were only partially captured in the Burial Book records, and the information below mainly results from the survey of Pink Cards (which were also used to compile the information in Chapter 8). Table 9 gives an indication of the variety of the physical and geometric properties of waste materials which may need to be taken into consideration.

Table 9. Physical and geometric properties of LFLS wastes

Waste type	Issue	Challenge
Ragged ends	Aluminium pieces from fuel cropping (no fuel contamination)	Potential reaction with some grouts.
Steel/plastic piping; steel or aluminium irradiation cans; steel drums	Void spaces	Grout infiltration. Repackaging if exhumed. Aluminium could react with some grouts.
Deuterium pump components	Void spaces and liquids	Grout infiltration. Release of contents.
Cables/wires	Complex geometry. Possibly unwound in the trenches	Complex geometry and repackaging if waste exhumed.
Sludge	Fine material	Grout infiltration. Health and safety aspects of repackaging (beryllium bearing dusts)
Filters	Size. Complex geometry. Void spaces.	Grout infiltration. Repackaging if exhumed.
Glove box	Size. Void spaces. Actinide contamination.	Grout infiltration. Repackaging if exhumed. At least 4 glove boxes were disposed to LFBG (3 in T51, 1 in T71).
Sodium light tubes	Void spaces	Grout infiltration.
Hypodermic needles	Health and safety	Potential injuries during repackaging.
Vacuum cleaner bags/contents	Fine material	Grout infiltration. Possible inhalation hazard on repackaging.
Demolition waste/ Timber	Geometry and accessibility	Grout infiltration
Ion exchange material	Fine material	Grout infiltration
Lead brick/lead camera/isotope pots	Lead toxicity	Acceptability for repackaging for future disposal.
PVC sheeting	Geometry	Repackaging if exhumed.
Large glass bottles and plastic carboys	Geometry and voidage	Grout infiltration. Repackaging if exhumed.
Liquids	Organic and inorganic	Grout compatibility with organic phases.
Broken glass	Possible injury	Operational safety
Asbestos may be present	Potential toxicity	Handling and disposal of asbestos (if present).

9.2. Non-Radiological Chemical aspects

9.2.1. Inorganic solvents

Records exist of the disposal of a wide range of chemical reagents into the trenches, including a variety of concentrated strong acids and bases such as: hydrochloric acid, phosphoric acid, nitric acid, chromic acid, fluorosulphonic acid (HSO_3F), and the strong base KOH.

After 50 years of burial, it is likely that some of these materials will have reacted with other trench contents and become neutralised, or diluted/ dissipated by rainfall inflows. However, some could remain in their original containers, and these may fail at some future time.

9.2.2. Organic solvents

Oily water, mineral oils, solvents and cleaning agents were disposed to LFBG. Much of this liquid was uncontaminated or of very low radioactivity, but some items contained various radionuclides. The Pink Card records referred to disposal of:

- Hydraulic, vacuum pump and lube oils
- Organic liquids such as toluene, xylene, methanol, n-octyl alcohol, acetone, benzol, carbon tetrachloride
- Turco™ cleaning agents.
- Contaminated toluene-based scintillation fluid
- Solvents characteristic of actinide recovery processes: such as kerosene and Tri Butyl Phosphate (TBP) used in the PUREX process for purification/recovery of actinides
- DSBPP (di-sec-butyl-phenyl-phosphonate), which was also used in actinide separation and particularly for extraction of U-233.

There is evidence of the burning of solvents at LFBG, which would presumably leave residual contamination, including radionuclides. Although it is unclear as to how commonplace the practice was, pink cards referring to the burning of 27.5 gallons of various solvents are recorded for T43 (1964) and there is also a record of waste xylene burned at the LFBG on 5/4/68[26] (see Section 2.4).

Analyses of trench waters and groundwater from the vicinity of the trenches have indicated that some of the organic compounds (for example TBP) can still be detected in the trench water samples, although 50 years have elapsed since disposal. While it may have been expected that these organic materials would have (at least partially) broken down and dispersed, this longevity may possibly be attributed to retention of liquids in containers for long periods (Rowling et al., 2017). The ongoing presence of organic materials might still facilitate enhanced actinide mobility near the LFLS trenches.

9.2.3. Biodegradable and potentially biological hazard items

The site contains a significant inventory of biodegradable items such as paper, wood and cardboard. There is some evidence for the disposal of some items that may have had a biological hazard associated with them, such as animal remains and urine samples. The presence of large amounts of disposed organic matter may facilitate bacterial activity which is considered to impact the mobility of actinides at the site (Vázquez-Campos et al., 2017).

[26] AAEC file note, dated 5 April 1968.

10. Issues raised after the disposal period of relevance to the inventory

10.1. Availability and relevance of records

As mentioned previously in this report, the LFBG/LFLS has been the subject of various discussions and investigations since disposals ceased, and these have been documented in the available files. Many of these discussions are only of tangential relevance to the disposals at LFBG and/or the inventory, and as such are not considered in detail in this report. For example, the AAEC was at one time considering re-opening the burial ground for additional disposals and was also searching for alternative disposal sites. Although potentially of historic interest, only a few details of these deliberations are relevant to the present report.

It should also be noted that there have been several previous reports by the AAEC and ANSTO related to the LFLS. These include a series of Environmental Monitoring reports, which can be accessed through the ANSTO website (e.g. Hoffmann et al. (2008)). Earlier AAEC reports include:

- Possible methods of disposal of AAEC's low and medium level solid radioactive waste and an environmental impact assessment of re-opening of an existing burial ground (Ellis, 1977)
- A study of the burial ground used for radioactive waste at the Little Forest area near Lucas Heights, NSW (Isaacs and Mears, 1977)
- The Little Forest Burial Ground - An Information Paper (AAEC, 1985)

The documents listed above were summarised in the early part of the current project (see discussion on pages 18-20 of Payne (2012)). More recently, the current research project has resulted in several additional reports, which have appeared since 2012. These are listed in Appendix A.

The sections below review some of the additional aspects of the preserved documents which are considered of relevance to evaluating the LFLS inventory.

10.2. Sludges

The radionuclide content of the sludges, particularly the alpha-emitting component, has received very little attention. Some estimates of the amounts of Co-60, Cs-137 and Sr-90 in the sludges were given in Isaacs and Mears (1977). These authors noted that the sludges were primarily hydrated aluminium oxide, but failed to mention the alpha-content of the sludges. A contemporary document[27] indicated that there were efforts underway to estimate the identity and concentration of alpha emitters in the solar evaporated sludges. However, this was in the context of a possible re-opening of the disposal site. It appears that this information was not intended to be used to assess the impact of the previous disposals. It is not known whether the measurements were actually completed.

10.3. Tritium

In 1978 P. A. Bonhote reported[28] on all available results of tritium at the burial ground (Figure 57). A plan of the sample boreholes was included. Boreholes D8 to D11 run in a north-south line between the trenches, with D10 being in the centre of the trenched area. The results suggested that tritium levels in groundwater were reduced after rainfall, which can be attributed to a dilution effect.

[27] New Burial Ground Working Party, Minutes, 12 September 1973.
[28] Tritium levels in boreholes at the burial ground. Minute of 13 Nov 1978.

Borehole	Nov.-Dec. 1975 (Drought)	February 1976 (After rain)
D7	800	300
D8	5,400	4,000
D9	3,800	1,800
D10	10,400	5,700
D11	1,400	1,600
D12	2,400	800
D13	200	100
D14	2,300	1,300
D15	7,200	700

Figure 57. Tritium results for LFBG boreholes in 1975-76 (pCi/mL).

Rough calculations indicate that a few curies of tritium would give rise to the observed levels. The most likely source seems to be material used to soak up heavy water spills in HIFAR. The amount of heavy water involved would be of the order of two litres, which could have come from a number of spills over a period of years.

Mr. Hespe has advised that monitoring of the burial ground boreholes for tritium is now routine. In addition, he will confer with Messrs Isaacs and Ellis to determine the most suitable sampling regime to establish whether concentrations in the off site boreholes are likely to increase or decrease in future.

Figure 58. Extract from a 1978 minute paper, which indicated that the source of tritium was likely heavy water from HIFAR.

According to a 1978 minute paper, the source of the tritium in LFBG groundwater was probably heavy water from HIFAR (Figure 58). However, the subsequent “Information Paper’ report (AAEC, 1985) stated that the detection of tritium in bore water within and outside the fenced area was unexpected as the AAEC did not “knowingly dispose” of any significant quantity of tritium. This statement is surprising given the data (and interpretation) reported in 1978. Furthermore, the pink cards (which should have been available to the author of the 1985 report) show abundant evidence of tritium disposals, including contaminated items constituting a tritium hazard (for example, Figure 50). It is very difficult to estimate the amount of tritium disposed at LFBG. Some packages contained tritium which had been absorbed by swabs and the number of swabs per package (as well as the total number of packages) is unknown. The amount of liquid (and tritium) associated with other types of waste packages is similarly uncertain. One method of estimating the tritium inventory is through modelling the extent of the tritium plume and the measured concentrations (Hughes et al., 2011).

10.4. Possible disposal of vehicles contaminated at Maralinga

During discussions undertaken within the research project, a few former AAEC employees mentioned that vehicles from Maralinga may have been disposed in the LFBG trenches. There is strong evidence that a number of vehicles from Maralinga were present on the Lucas Heights site in 1987[29]. These were subsequently decontaminated and buried at a local landfill. There is no evidence that any vehicles were disposed in the trenches during the operations at LFBG. Intact vehicles would not have fitted into the trenches and there is no evidence such as ground disturbance or geophysical anomalies to suggest the presence of large objects such as motor vehicles elsewhere on the LFLS site.

10.5. Explanation of Pu presence and mobility

The presence of plutonium contamination at the ground surface (which was first observed during the early 1970s) was considered to be surprising by the contemporary AAEC staff. The detection of plutonium highlighted both that Pu had been disposed at the site and also that a potential mobilisation mechanism for Pu existed. Both of these findings led to an increased concern about the disposals which had been undertaken, and the possible ramifications of environmental releases from the site.

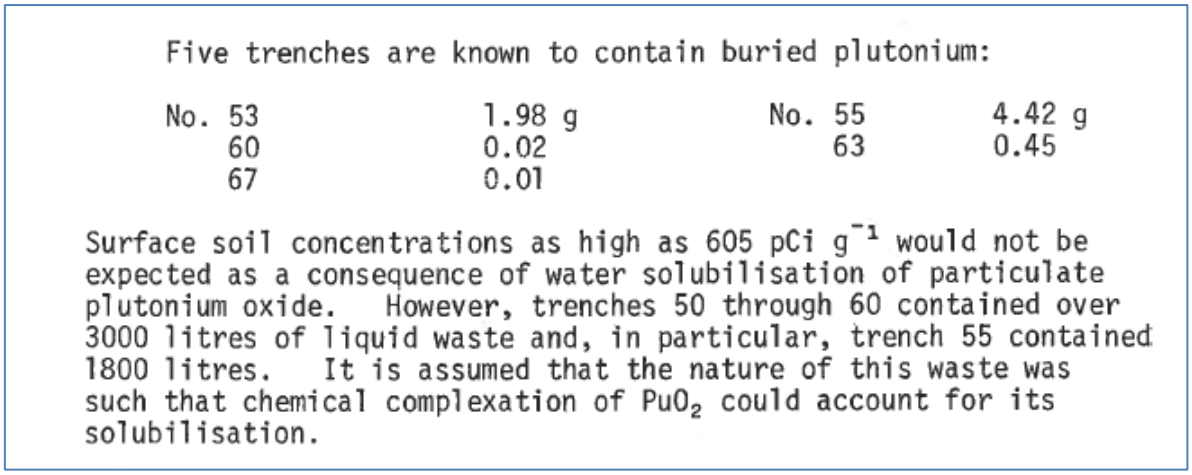
Further detections of Pu resulted in extensive follow-up investigations (Figure 59). Both Pu-239 and Am-241 were detected. The presence of these actinides was attributed to Pu which had resulted from research undertaken by the AAEC, and was believed to have been disposed in the form of Pu-nitrate (see discussion in Figure 52). The Am-241 is a decay product of Pu-241, which was present in the wastes disposed at the LFBG, although was rarely listed among the disposed isotopes.

1. A sample of soil taken at ground level, near Trench 57 of the burial ground had been analysed in November 1982 for plutonium by solvent extraction and alpha spectrometry, and found (unexpectedly) to contain 330 pCi g^{-1} of Pu 239/240. In an attempt to gain further information on this plutonium and its origin, more investigations were carried out on this sample and also on a "background" soil

Figure 59. Investigation of Pu in soils undertaken in 1982.

In 1984 Mr D. Davey[30] provided a discussion of the possible reasons why plutonium was present and apparently mobile in the vicinity of Trench 55 (Figure 60). This was attributed to the presence of complexants in liquid wastes also disposed in these trenches. Similar conclusions about the possible role of complexants have also been raised during the current project (Rowling et al., 2017) and are also discussed in Chapter 9.

[29] Minute paper by Mr JCE Button dated 4 May 1987.
[30] Minute paper to Mr Bonhote of 16 August 1984.



Five trenches are known to contain buried plutonium:

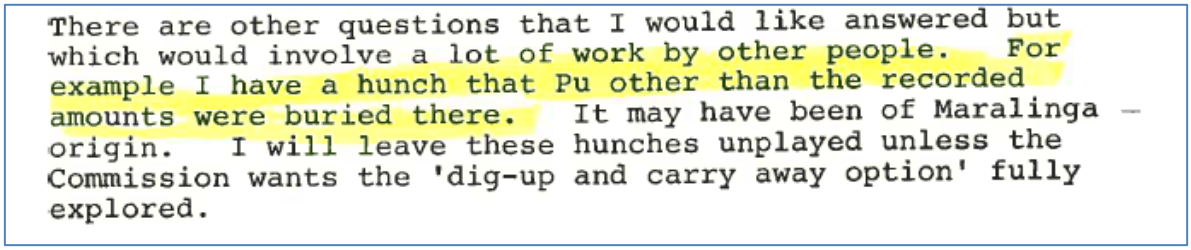
No. 53	1.98 g	No. 55	4.42 g
60	0.02	63	0.45
67	0.01		

Surface soil concentrations as high as 605 pCi g^{-1} would not be expected as a consequence of water solubilisation of particulate plutonium oxide. However, trenches 50 through 60 contained over 3000 litres of liquid waste and, in particular, trench 55 contained 1800 litres. It is assumed that the nature of this waste was such that chemical complexation of PuO_2 could account for its solubilisation.

Figure 60. An early recognition that the release of plutonium from the trenches could be partly due to the presence of complexants found in liquid wastes.

10.6. Inventory uncertainty

We have already discussed the inconsistencies in the beryllium inventory (Section 5.3.1). Following the cessation of disposals there were some doubts raised about the accuracy of other aspects of the LFLS disposal inventory. The records show that senior staff have raised issues about the completeness of the burial records at LFBG. For example, Mr D. Davey (then head of Environmental Science division) stated[31] that additional Pu (other than that already reported) may have been disposed in the trenches (Figure 61). He suggested that the additional Pu could have "been of Maralinga origin", although we have not found any evidence in the available records to support this suggestion. However, the descriptions of the known Pu-containing items from the Lucas Heights facility disposed at LFBG suggest that other similar items from the same laboratories may have contained additional Pu, which was not reported (see discussion in Section 5.5).



There are other questions that I would like answered but which would involve a lot of work by other people. For example I have a hunch that Pu other than the recorded amounts were buried there. It may have been of Maralinga – origin. I will leave these hunches unplayed unless the Commission wants the 'dig-up and carry away option' fully explored.

Figure 61. Speculation on whether additional amounts of plutonium may have been buried at LFBG.

10.7. Conclusion

The evidence given in this chapter shows that various issues had been raised in the years subsequent to LFBG disposals about the radionuclide content of the sludge drums, presence of tritium, disposal of liquid wastes (containing actinide complexing agents), and uncertainty in the inventory. These questions have been followed up in the current research project undertaken at LFLS. In many cases further evidence has been collected to evaluate the possible issues associated with these questions.

[31] Minute paper to Dr D.G. Walker from D. Davey, 1984.

11. Summary

The current report has aimed to provide the information required for interpreting the events which took place during disposal operations at the LFBG. We have reviewed all the available records, and established relationships between the different types of documents. In particular, we have examined how the existing inventories were derived from the disposal documents, and identified various inconsistencies in these records. Some key insights have been presented regarding:

- The implementation of disposal operations, including the incineration of some objects on the site (Section 2.4)
- The role of the burial ground store for decay-storage of wastes (Figure 1)
- The original documentation of the disposals, including pink cards, Waste Burial Books (WBBs) and Scrap Disposal Reports (SDRs) (Chapter 2)
- The documentation of actinides, including U-233 and Pu, on the SDRs (Section 3.2)
- How the summary records were assembled. In particular we have examined how key documents such as the WBRs and the subsequent EHM relied entirely on the SDRs to evaluate the actinides disposed (Section 3.2).
- The possibility that the amount of Pu disposed may have been underestimated, because *only* the Pu recorded on the SDRs was included in the previous inventory. The estimates of Pu and U-233 disposed were based on a very small number of the SDR records (<10 in both cases)
- The other items disposed at LFLS (approximately 50,000) must be assumed to contribute a negligible amount to the Pu inventory in order for the estimates of total Pu disposals to be considered reliable (Section 3.2)
- The rule-of-thumb methods which were apparently used to estimate the beryllium disposals, and how differing estimates of the beryllium disposed have been propagated (Section 5.3). Similar methods were also used to estimate the Groups II and III content of the sludge drums.
- The categorisation of wastes into Groups I, II and III; and the estimation of the amounts of radionuclides in these groups (mostly using surface dose rates for Group II and III)
- The importance of the contents of the sludge drums (particularly their actinide content), and the omission of approximately 75% of the Group I inventory of these drums from the disposal record (Section 6.1)
- The significant underestimation of the Group I Inventory - due to the omission (from the Group I calculations) of the Pu reported on the SDRs (Section 6.5)
- The gradual relaxation of the dose-limit requirements for disposals during the disposal era (Section 7.1).
- The accelerations of disposals towards the end of LFBG operations, resulting from relaxed dose-limits, emptying out of higher activity items from the burial ground store, and possible confusion about the application of limits mentioned in the criticality certificate
- The loss of approximately 90% of the pink cards for disposed items
- The types of items disposed (as reported on the available pink cards), including “Ragged Ends”, “Tritium Hazard” items, and other components from reactor operations (Sections 8.5.3; 8.9.4)
- The poor documentation of disposals for trenches filled in the final year of disposals, and evidence that some disposed items were not reported (Section 8.9.6)
- Possible reasons why the disposals at LFBG ceased in 1968 (Section 7.11)
- Various errors and omissions in the previous inventories, resulting from oversights, confusion, and typographical errors (Section 6.3).

The above findings facilitate the calculation of an improved inventory for estimating the dose consequences of the radionuclides present at the LFLS. They summarise a substantial amount of effort over many years, and considerably add to the available knowledge about the LFLS site.

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Appendix A: Related documents from research at the LFLS

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Stuart Hankin (2012). Little Forest Burial Ground - Geology, Geophysics and Well Installation. ANSTO E-781. Australian Nuclear Science and Technology Organisation.

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Appendix B: Counts of Pink cards[32]

Trench.	Box No.	Total no. of cards	Cards counted in each category [127x200mm cards]								Smaller cards (100 x 65 mm)
			LL	LLB	LS	LSB	MS	FMS	HL	HS	
13*		5	5								
21		3	3								
23		1	1								
23/24**		5	5								
28		3	3								
29		1	1								
38		3	3								
43		5	5								
46		10	10								
50		138	1			137					
51		66				66					
52		85	1			84					
53		141	1			140					
54		1				1					
55		49	9	34		6					
62		10	3			7					
63	1 of 2	234				234					
63	2 of 2	196				196					
64		236	15	6		215					
65		16				16					
66		215	1			214					
68	1 of 2	299	1		3	295					
68	2 of 2	262			63	141					58
69	1 of 2	390	2		56	270					62
69	2 of 2	210				210					
70	1 of 4	130			33	62					35
70	2 of 4	120			2	115			1		2
70	3 of 4	231			1	230					
70	4 of 4	234				234					
71	1 of 3	273			3	269	1				
71	2 of 3	208				146	62				
71	3 of 3	191			1	154	30		6		
72		215			1	8	176	6		6	18
73		196					145			51	
74		134			1	2	116	2		13	
75		139					138			1	
76		153					152			1	
	total =	4810	62	51	165	3450	820	8	7	72	175

*Items burned at an unknown location

**Items disposed between the dates of trenches.

[32] This information was derived by counting the numbers of cards in each storage box (originally many of these were bundles tied with string). Note that many trenches are not represented in this summary table (i.e. no pink cards exist for these trenches).

Appendix C: Number of records in Waste Burial Books and Burial Ground Store book[33]

LL = Low level liquid, LLB = Low level liquid with beryllium, LS = Low level solid, LSB = Low level solid with beryllium; MS = medium solid; HS = high level solid, HL = high level liquid; F = Fissile

Trench	*Source*	*Total No. of items in trench*	*Records counted in each category*								
			LL	*LLB*	*LS*	*LSB*	*MS*	*FMS*	*HS*	*HL*	*F*
1	n/a	0	0	0	0	0	0	0	0	0	0
2	n/a	0	0	0	0	0	0	0	0	0	0
3	n/a	0	0	0	0	0	0	0	0	0	0
4	n/a	0	0	0	0	0	0	0	0	0	0
5	n/a	0	0	0	0	0	0	0	0	0	0
6	WBB1	93	0	0	93	0	0	0	0	0	0
7	WBB1	311	0	0	58	253	0	0	0	0	0
8	WBB1	308	0	0	250	58	0	0	0	0	0
9	WBB1	214	0	3	86	125	0	0	0	0	0
10	WBB1	507	0	0	307	200	0	0	0	0	0
11	WBB1	297	0	0	200	97	0	0	0	0	0
12	WBB1	201	0	0	82	119	0	0	0	0	0
13	n/a	0	0	0	0	0	0	0	0	0	0
14	WBB1	248	0	0	192	56	0	0	0	0	0
15	WBB1	291	0	0	183	108	0	0	0	0	0
16	WBB1	585	0	0	403	182	0	0	0	0	0
17	WBB1	513	0	0	307	206	0	0	0	0	0
18	WBB1	558	0	0	314	244	0	0	0	0	0
19	WBB1	619	0	0	407	212	0	0	0	0	0
20	WBB1	267	0	0	135	132	0	0	0	0	0
21	WBB1	800	3	8	525	264	0	0	0	0	0
22	WBB1	520	0	2	401	117	0	0	0	0	0
23	WBB1	553	1	1	218	333	0	0	0	0	0
24	WBB1	566	0	0	301	265	0	0	0	0	0
25	WBB1	347	0	0	262	85	0	0	0	0	0
26	WBB1	656	0	2	64	590	0	0	0	0	0
27	WBB1	304	0	4	205	95	0	0	0	0	0
28	WBB1	496	4	5	454	33	0	0	0	0	0
29	WBB1	685	1	0	100	584	0	0	0	0	0
29(a)	WBB2	214	0	0	0	214	0	0	0	0	0
30	WBB2	97	0	0	32	65	0	0	0	0	0
31	WBB2	499	0	6	468	25	0	0	0	0	0

[33] The information in this table was derived by counting the number of items recorded in burial books.

Trench	Source	Total No. of items in trench	Records counted in each category								
			LL	LLB	LS	LSB	MS	FMS	HS	HL	F
32	WBB2	789	0	1	75	713	0	0	0	0	0
33	WBB2	887	0	13	342	532	0	0	0	0	0
34	WBB2	789	1	0	256	532	0	0	0	0	0
35	WBB2	862	0	0	396	466	0	0	0	0	0
36	WBB2	421	0	0	46	375	0	0	0	0	0
37	WBB2	549	0	0	207	342	0	0	0	0	0
38	WBB2	734	3	8	265	458	0	0	0	0	0
39	WBB2	694	1	0	242	450	0	0	1	0	0
	Burned in pit	15	8	7	0	0	0	0	0	0	0
40	WBB2	762	0	0	347	415	0	0	0	0	0
41	WBB2	190	0	0	1	189	0	0	0	0	0
42	WBB2	424	0	0	203	221	0	0	0	0	0
	Burned in pit	24	7	17	0	0	0	0	0	0	0
43	WBB2	688	2	6	229	448	0	0	0	0	0
44	WBB2	479	0	0	55	424	0	0	0	0	0
45	WBB2	994	0	0	375	614	0	0	5	0	0
46	WBB3	958	1	9	186	762	0	0	0	0	0
47	WBB3	759	0	0	402	357	0	0	0	0	0
48	WBB3	851	0	0	194	657	0	0	0	0	0
49	WBB3	1025	0	0	530	495	0	0	0	0	0
50	WBB3	785	1	0	324	460	0	0	0	0	0
51	WBB3	866	0	0	380	483	0	0	0	3	0
52	WBB3	822	0	0	455	367	0	0	0	0	0
53	WBB3	465	0	1	75	389	0	0	0	0	0
53	WBB-1966	11	0	0	11	0	0	0	0	0	0
54	WBB-1966	790	0	0	354	436	0	0	0	0	0
55	WBB-1966	592	22	41	198	331	0	0	0	0	0
56	WBB-1966	450	0	0	0	450	0	0	0	0	0
57	WBB-1966	740	21	0	433	286	0	0	0	0	0
58	WBB-1966	581	2	3	277	299	0	0	0	0	0
59	WBB-1966	764	2	4	0	757	0	0	0	0	1
60	WBB-1966	506	1	4	226	271	0	0	0	0	4
61	WBB-1966	362	1	5	123	233	0	0	0	0	0
62	WBB-1966	356	3	0	349	4	0	0	0	0	0
63	WBB-1966	443	0	0	0	427	0	0	0	0	16
64	WBB-1966	310	15	7	68	220	0	0	0	0	0
65	WBB-1966	634	1	0	236	396	0	0	0	0	1
66	WBB-1967	635	0	1	59	574	0	0	0	1	0
67	WBB-1967	831	5	9	521	281	0	0	0	5	9

Trench	Source	Total No. of items in trench	Records counted in each category								
			LL	LLB	LS	LSB	MS	FMS	HS	HL	F
67(a)	BGS Book	910(c)	5	5	453	433	0	0	0	5	9
68	BGS Book	61	0	0	61	0	0	0	0	0	0
69	BGS Book	691	1	0	17	672	0	0	0	1	0
70	BGS Book	505	0	0	16	489	0	0	0	0	0
71		0 (b)									
72		0									
73		0									
74		0									
75		0									
76		0									
S1	WBB-1966	333	6		16	311					
S2		0									
	TOTALS[34]	36172	113	167	14597	21248	0	0	0	16	31

Notes:

a) Disposals in Trenches 29 and 67 were recorded in two books

b) 1503 pink cards exist for trenches 71 to 76. These items are not recorded in any burial book.

c) The items in the BGS for trench 67 are apparently repeated in the WBB and are not included in the total record count.

[34] According to Isaacs and Mears (1977, p2) a total of 47600 packages were disposed at the LFBG.

Appendix D: Summary of wastes disposed in trenches[35]

Trench number	Date Filled	Type of waste and containers		Comments	No. of sludge drums
1	NR	FB Drums and Hand Waste	T		
2	NR	FB Drums and Hand Waste	T		
3	NR	FB Drums and Hand Waste	T		
4	NR	Ducting and Filters			
5	26/11/60	Sludge Drums			Possibly 4
6	6/1/61	Low solid in SK Bags	T		
7	13/1/61	LS in SKB and LSB	T		
8	23/2/61	LS in SKB and LSB	T		
9	8/3/61	LS in SKB and LSB	T	30 Gals Waste Oil	
10	11/5/61	LS in SKB and LSB and FD	T		
11	29/5/61	LS in SKB and FD and LSB	T		
12	3/7/61	LS in SKB and FD and LSB	T		
13	NR	Liquid		313.5 gal.	
14	14/7/61	LS in SKB and FD and LSB	T	Includes 2.4 m^3 of Wood Waste	
15	2/8/61	LS in SKB and FD and LSB	T		
16	28/9/61	LS in SKB and FD and LSB	T		
17	27/10/61	LS in SKB and FD and LSB	T		
18	13/12/61	LS in SKB and FD and LSB and filters	T		
19	5/3/62	LS in SKB and FD and LSB	T		
20	22/3/62	LS in SKB and FD and LSB	T		
21	9/6/62	LS in SKB and FD and LSB and Liquid	T	81 Gal waste liquid	
22	1/8/62	LS in SKB and FD and LSB	T	0.56 Gal. liquid	
23	3/9/62	LS in SKB and FD and LSB	T	0.5 gal liquid waste. Steel tray. 72 Gals. Org. solvent	
24	18/10/62	LS in SKB and FD, LSB & 16PB	T		
25	7/12/62	LS in SKB and FD and LSB & PB	T		
26	15/12/62	LS in SKB and FD, LSB & PB	T	Box, 3.5 gal. org. solvent	
27	25/1/63	LS in SKB and FD, LSB, PB	T	15 gal org. solv. In steel drums (OS/SD)	

[35] The information in Appendix D is based on the source document "Estimates of Hazardous Materials Buried at the Little Forest Burial Ground" (also referred to herein as the "EHM"). This document has been converted to an electronic form and can also be found in ANSTO records.

Trench number	Date Filled	Type of waste and containers		Comments	No. of sludge drums
28	3/4/63	LS in SKB and FD, LSB, PB	T	30.5 Gal OS/SD I box	
29	18/4/63	LS in SKB and FD, LSB, PB	T		
30	23/4/63	LS in SKB, LSB and PB	T	13.5 m of LLSW from CEMB	
31	9/7/63	LS in SKB, LSB and PB	T	18 Gal OS/SD	
32	17/8/63	LS in SKB, LSB and PB	T		
33	21/9/63	LS in SKB, LSB in FD and PB	T	8.91 gal OS/ISD rest. pol. bottles	
34	30/10/63	LS in SKB, LSB in FD & PB	T	4 Gal OS/SD	
35	18/12/63	LS in SKB, LSB in FD & PB	T		
36	21/12/63	LS in SKB, LSB in FD & PB	T	Pusher furnace	
37	8/2/64	LS in SKB, LSB in FD & PB	T	44 gal. drum	
38	25/3/64	LS in SKB, LSB in FD & PB	T	10 x 44 gal of U ore from UNSW	
39	2/5/64	LS in SKB, LSB in FD & PB	T	29 x 44 gal. drums of solidified sludge (DSS)	29
40	27/6/64	LS in SKB, LSB in FD & PB	T	4 gal. OSSD 39X44 gal DSS	39
41	11/7/64	LSB in FD & PB solidified sludge	T	77x44 gal. DSS 1 filter unit.	77
42	6/8/64	LS in SKB, LSB in FD, solidified sludge & PB	T	66x44 gal DSS	66
43	16/9/64	LS in SKB, LSB in FD, solidified sludge & PB	T	16.37 gal solvent 39x44 gal. DSS	39
44	1/10/64	LS in SKB, LSB in FD, solidified sludge & PB	T	38x44 Gal DSS	38
45	16/11/64	LS in SKB, LSB in FD & PB	T	Cutting/Grinding Machine ex B19.	
46	16/12/64	"	T	6 large packages 0.3 to 0.8 m^3	
47	11/3/65	"	T	1.4 m^3 filters	
48	28/4/65	"	T		
49	15/7/65	LS in SKB, LSB in FD & PB plus solidified sludge.	T	49x44 gal DSS 3 wooden boxes	49
50	29/9/65	LS in SKB, LSB in FD and PB	T	130 gal. LL liquid	
51	14/10/65	"	T	5 large packages 1.1 to 5.1 m^3	
52	14/12/65	" and filters	T	3.7 m^3 filters	
53	23/12/65	LS in SKB, LSB in FD & PD & ducting filter drums.	T	Ducting filters 37x44 Gal DSS	37
54	9/3/66	LS in SKB, LSB in FD & PB & dried sludge & liquid	T	13x44 gal DSS	13
55	6/4/66	LS in SKB, LSB in FD & PB	T	403 gal liquid waste	
56	11/6/66	"	T		

Trench number	Date Filled	Type of waste and containers		Comments	No. of sludge drums
57	19/7/66	" and liquid	T	147 gal liquid waste buried	
58	2/9/66	"	T	21.25 gal liquid waste.	
59	21/10/66	"	T	49.5 gal. liquid waste.	
60	17/11/66	"	T	20 gal. liquid waste.	
61	26/11/66	" and sludge	T	49.5 gal. liquid waste. 55x44 gal. drums sludge.	55
62	14/3/67	"	T	1.25 gal liquid waste	
S1	16/3/67	LS in SKB, LSB in FD & PB & Liquid	T	19.5 gal liquid waste	
63	18/3/67	LS in SKB, LSB in FD & PB and sludge.	T	13x44 gal drum sludge.	13
64	12/4/67	" and liquid	T	36x44 gal drum sludge. 160 gal liquid waste.	36
65	20/6/67	LS in SKB, LSB in FD & PB & sludge.	T	30x44 gal drum sludge. 0.5 gal liquid waste.	30
66	26/7/67	LS in SKB, LSB in FD & PB	T	16x44 Gal drum sludge, 1 gal liquid waste.	16
67	14/10/67	LS in SKB, LSB in FD & PB	T	16 gal. liquid waste	
68	23/10/67	LS in SKB, LSB in FD & PB	T	39x44 Gal. drum sludge.	39
69	7/11/67	LS in SKB, LSB in FD & PB	T	6x44 gal. drum sludge.	6
70	22/11/67	LS in SKB, LSB in FD & PB	T	12x44 gal. drum sludge.	12
71	9/2/68	LS in SKB, LSB in FD & PB		32x44 Gal. drum sludge.	32
72	5/4/68	LS in SKB, LSB in FD & PB		27x44 Gal. drum sludge.	27
73	8/7/68	LS in SKB, LSB in FD & PB		51 FB Drums containing 930 gms Be.	(39[A])
74	12/8/68	LS in SKB, LSB in FD & PB		22x44 Gal. sludge drums 12 comp. filters	22
75	8/11/68	LS in SKB, LSB in FD & PB	T	Multivee filter, 1 glove box. Boxes ex-CSIRO Adelaide.	0
76	22/11/68	"		85x44 gal sludge drums-multivee filters.	85
S2	8/4/68	25 x 5 drums ex ex-Uni. Of Sydney.			
				Total sludge drums	**760 (799[A])**

[A] 39 sludge drums were disposed in trench 73 but were omitted from the EHM document.

See next page for explanation of abbreviations.

ABBREVIATIONS:

NR	Not recorded
Neg.	Negligible
SKB	Sisalkraft bag
LS	Low Level Radioactive Solid Waste
FD	Fibreboard Drum
LSB	Low Level Radioactive Solid Waste Contaminated with Beryllium
T	Normal laboratory trash
OS/SD	Organic solvent in steel drums
DSS	Drums of solid sludge
PB	Polythene bag

Notes:

Until SAP/P5 was approved on 26 July 1967, all waste buried was classified as low level and had a dose rate less than 5 mR/hr.

After SAP/P5 was introduced, the waste burial records were examined and the buried waste was re-assessed as either low-level (<2.5 mR/hr) or medium level (2.5 mR/hr to 200 mR/hr) so that records would be consistent with SAP/P5.

The recorded radioactivity and beryllium content of the waste was based on estimates provided by the originators of the waste.

Waste Management Section also estimated the radioactivity of the waste by measuring the surface dose rate on the packaged waste and comparing it to a standard.

To the best of staff recollection, a new trench (No. 77) was half dug when the direction to close the burial ground was received.

The half dug trench was then back-filled with inactive waste collected in the burial ground area in the final clean up.

Appendix E: Waste volume, beryllium and radionuclide inventory of trenches[36]

Trench No.	Waste Volume (m^3)		Estimated activity (mCi)			Fissile content (grams)			Fertile content (Kg)		Be / BeO
	Low level	Medium level	Group I	Group II	Group III	Pu	U-233	U-235	U	Th	Kg
1	NR		Neg.								
2	NR		Neg.								
3	NR		Neg.								
4	NR		Neg.								
5		0.8		0.1							
6	2.4		Neg.								
7	1.6	10.8	Neg.	0.2							13.4
8	6.9	2.4		0.1							4.9
9	2.3	5.3	Neg.	1.0	1.1						6.1
10	8.5	8.5	*(1)#*	1.0	1.1						10.4
11	5.3	4.1		0.1							5.5
12	2.3	5.9		0.2	0.1				0.3	0.9	6.8
13											
14	5.3	6.8		1.0	1.5					1.4	3.5
15	5.2	4.6		0.1							6.2
16	11.4	8.9		0.1							9.3
17	8.5	8.6		0.1							10.8

[36] The information in Appendix E is based on the source document "Estimates of Hazardous Materials buried at the Little Forest Burial Ground". This document is also referred to as the EHM document. This document is stored in ANSTO records, and an electronic version has also been made.
# indicates a transcription error (see Figure 49 and accompanying discussion).

Trench No.	Waste Volume (m^3)		Estimated activity (mCi)			Fissile content (grams)			Fertile content (Kg)		Be / BeO
	Low level	Medium level	Group I	Group II	Group III	Pu	U-233	U-235	U	Th	Kg
18	9.8	10.2						5.3			12.9
19	11.6	9.1		0.1				11.63			11.1
20	4.0	5.8		0.1							7.5
21	14.2	12.3		0.1	0.1						15.5
22	10.8	5.7		0.1							5.7
23	5.2	14.1		0.1	0.1						18.0
24	8.8	16.6		0.1							10.1
25	9.2	4.4		0.1							4.8
26	1.9	25		3.5	6.0			12.0			32.7
27	5.8	4	Neg.	Neg.							5.4
28	12.8	1		0.1							1.9
29	2.9	24.8		0.4	1.0						32.3
30	14.3	2.7		0.2	0.3						3.7
31	13.3	3.3		Neg.							1.4
32	2.3	30.5		0.1	0.1						39.7
33	9.8	27.4		0.1	0.1						29.4
34	7.2	22.5		2.0	2.1						29.4
35	11.3	20.3		1.1	2.0						25.6
36	1.3	16.3									20.4
37	5.9	14.6		0.1							18.5
38	13.9	18.1		3.0	0.1			1.98			25.2
39	6.9	23.5		7.4	7.4						25.3
40	10.6	26		9.8	9.9						22.7

Trench No.	Waste Volume (m^3)		Estimated activity (mCi)			Fissile content (grams)			Fertile content (Kg)		Be / BeO
	Low level	Medium level	Group I	Group II	Group III	Pu	U-233	U-235	U	Th	Kg
41		19.1		19.3	19.3			16.22			9.5
42	5.8	18.5		16.6	16.6						11.4
43	6.5	25.7		10.2	10.3						24.5
44	1.6	23.6		9.7	9.7						23.2
45	11.7	27.7		1.2	1.2				3.8		34.3
46	5.3	37.2		0.4	0.4						42.5
47	11.3	18.2		0.3	0.4		1.17				NIL
48	7.0	28.5		1.3	2.0		1.14		4.1	4.00	35.5
49	15.1	28.8		12.6	12.6						26.5
50	9	27.8		0.8	1.4			8.9			25.0
51	10.5	33		0.1	0.1				0.2	14.6	24.0
52	14.9	22.9		0.2	0.3						19.4
53	2.1	24.4		9.4	9.4	1.98					21.0
54	10.1	22		3.4	3.4						23.9
55	5.8	15.8		0.4	0.4	4.42	0.4	13.42			17.3
56		19.1		0.1	0.1						24.6
57	14.4	11.8		1.3	2.0						10.4
58	8.3	12.7		2.0	2.0			4.14		0.02	16.1
59		32.5		0.2	0.3					2.5	42.8
60	6.4	13.9		1.4	2.0	0.02			0.32	3.1	14.4
61	3.6	18.9		14.0	14.0						8.1
62	9.5	0.2		Neg.							0.3
S1	0.5	19		12	13.5						20.9

Trench No.	Waste Volume (m^3)		Estimated activity (mCi)			Fissile content (grams)			Fertile content (Kg)		Be / BeO
	Low level	Medium level	Group I	Group II	Group III	Pu	U-233	U-235	U	Th	Kg
63		21		15	15.4	0.45		3.83	40.3	12.3	24.6
64	2.0	14.1		41	41.7						11.8
65	12.4	21.5		25	25.8						21.8
66	1.7	28		26.0	26.9						31.9
67	15.1	12.5		0.6	0.7	0.01	2.50	11.13	6.8	0.06	15.4
68	16.6	10.2		80.0	95.0					1.0	6.3
69	15.1	14.4		20	29						16.1
70	3.6	32.3		90	181						36
71	19.8	20.3	2.6	301.5	1150			2.63	0.86	5.73	1
72	15.8	10.4	1.2	137	667			0.78			0.1
73	14.6	13.1	0.7	38.3	238.1						1.723
74	19.3	7.2	0.4	27.6	221.1				2.55		0.4
75	28.6	5.3	8.1[37]	40.4					0.04	2.44	0.06
76	3.8	14.9	6.3	57.8	170.9						0.55
S2	0.6			Neg.							
TOTAL	**581.9**	**1131.4**	**19.3**	**1049.6**	**3017**	**6.88**	**5.21**	**91.96**	**59.27**	**48.05**	**1119**

Note: It appears that the SDRs reported in Appendix F were used to compile fissile and fertile inventories in the EHM document (which is the source of Appendix E). There are minor inconsistencies between the two tabulations, for example, between the amounts of U-233 (due to the confusion of the fate of SDR 29: the U-233 in this SDR appears double-counted in both trenches 47 and 48 in the EHM, but may have actually been split between trenches 47 and 48). Similarly, there was U-235 content in several of the SDR items which were discarded into the treatment plant (Table 1), which probably ended up in buried sludges at LFLS but was not accounted for in the EHM inventory.

[37] The entries for Group I and Group II in Trench 75 appear anomalous. The Figure of 8.1 mCi under Group I should probably be in the column for Group II, and the Figure for Group II should be under Group III. See Section 5.1.1.

Appendix F: Summary of Scrap Disposal Reports

		ISOTOPES PRESENT						
SDR No.	**Trench buried**	**Th-232 (Kg)**	**Dep U (Kg)**	**U_{nat} (Kg)**	**U-235 (g)**	**U-233 (g)**	**Pu (g)**	**Short Description**
1								SDR not available
2	12	0.9						Th metal turnings, mixed with rubber in paraffin
3	12			0.3				U metal powder mixed with graphite
4	14	0.8						Th metal powder in coke and pitch
5	14	0.6						Th metal powder in coke and pitch
6	51			0.2				U metal powder in coke and pitch
7	51	5.8						Th metal powder in coke and pitch
8	Treatment plant (Nov 61)				10.8			Uranyl nitrate with Al nitrate in solution
9	Long term storage							N/A
10	Treatment plant (Aug 62)				0.19			U-235 oxide suspension
11	26				5.8			Analytical residues
12	38				3.95			1L of mixed liquid phases (organic, acid, etc)
13	26				0.02			Analytical residues
14	26				0.03			Analytical residues
15	26				2.3			UO2-beryllium oxide, in tissues
16	26				2.15			Glove box waste in tissues
17	26				1.7			U-nitrate, organic solvent, apparently burned
18	26				5.3			U-nitrate, organic solvent, apparently burned
19	26				11.63			Waste as sludge with BeO, Th, U-235, etc
20	38				0.18			UO2 with Th, Be
21	38				0.6			UO2 glove box waste
22	Treatment plant (1963)				8.65			Dilute suspension in liquid waste drums
23	Long term storage							N/A
24	Long term storage							N/A
25	41				16.22			Machining sludge (project 1.3.4)
26	Long term storage							N/A
27	45			3.8				BeO-UO2 waste from production of blocks for reactor physics
28	48	4.0		4.1				Nat UO2 and ThO2 powder-particles, some coated with BeO

		ISOTOPES PRESENT						
SDR No.	**Trench buried**	**Th-232 (Kg)**	**Dep U (Kg)**	**U_{nat} (Kg)**	**U-235 (g)**	**U-233 (g)**	**Pu (g)**	**Short Description**
29	47, 48					1.14		U oxide, enriched in U-233, 100 contaminated lead bricks
30	Presumed buried		12.5					Fabrication off cuts. Presumed buried 1965
31	51	1.5						Mixture of Th and Be
32	51	3.8						Mixture of Th and Be
33	51	3.5						Mixture of Th and Be
34	55						0.72	Plutonium as waste contained in tissues (glove box cleanings)
35	55						3.7	Plutonium as waste contained in tissues (glove box cleanings)
36	50				2.86			U-Th oxide co-precipitate
37	50				1.06			U-Th oxide co-precipitate
38	50				4.98			U-Th oxide co-precipitate (waste material from fuel specimens)
39	53						1.98	Pu waste in tissues with BeO
40	55					0.4		U-233 In various solutions
41	55				12.21			Glove box cleanings (fibre drums), jars of U-Th-nitrate solution
42	68				7.44			2.25 litres of uranyl nitrate
43	55				1.21			Jars totalling 1.5 litres
44	68	0.5		0.5				Co-precipitate (U-Th) presumed equal U or Th
45	63						0.15	Waste from fabrication of Pu-Al cermets
46	58	0.02			4.14			Co-precipitated U-Th material as powders and sinters. The U content was reported as 93% U-235
47	Long term storage							N/A
48	60	0.2		0.02				Waste from fuel particle production
49	60	3.1		0.3				Ammonium di-uranate and Th-OH, in a jar, sealed in polythene envelope, inside bag, etc
50	Long term storage							N/A
51	59	2.5						Natural Th powder mixed with Ca F
52	Long term storage							N/A
53	Long term storage							N/A
54								SDR not available
55								SDR not available
56	60						0.02	Pu in tissues glove box waste
57	63				3.16			Compacts containing enriched uranium
58	Long term storage							N/A

		ISOTOPES PRESENT						
SDR No.	**Trench buried**	**Th-232 (Kg)**	**Dep U (Kg)**	**U_{nat} (Kg)**	**U-235 (g)**	**U-233 (g)**	**Pu (g)**	**Short Description**
59	63		39					Metal swarf in kerosene. Sealed metal drums.
60	Long term storage							N/A
61	Long term storage							N/A
62	63	12.3		1.3				Coprecipitate and tissue waste
63								SDR not available
64	63						0.3	Pu-oxide waste in tissues. Multiple packing (paint-tins, etc)
65	63				0.67			Fused samples in crucibles
66	67	0.02			1.68			Waste material from rig manufacture
67	67	0.04			7.96			Waste material from rig manufacture
68	Unknown	25.3		2.4				6 fibre drums of which 2 were likely buried.
69	67			6.8				Waste in tissues, fibre drums.
70	Long term storage							N/A
71	65						2.8 E-5	Alpha standards
72	67					0.2652		Specimens of U-233 in graphite
73	67				1.49			U-235 fuelled BeO compacts, control specimens
74	Unknown					0.16		
75	Long term storage							N/A
76	Long term storage							N/A
77	Long term storage							N/A
78	Long term storage							N/A
79	67					0.23		Scrap U-oxide plus carbon
80	67					2.00		Prills and loose powder containing U-233
81	67						0.01	Glove box waste
82	Long term storage							N/A
83	Long term storage							N/A
84	Long term storage							N/A
85	Long term storage							N/A
86	71	0.5		0.28				U-Th-O2 in BeO, tissues and powder
87	71	0.2						Th-O2 in tissues, contaminated powder

		ISOTOPES PRESENT						
SDR No.	**Trench buried**	**Th-232 (Kg)**	**Dep U (Kg)**	**U_{nat} (Kg)**	**U-235 (g)**	**U-233 (g)**	**Pu (g)**	**Short Description**
88	71	1.3		0.1				U-Th-O2 in BeO, tissues and powder
89	71	1.63						Th-O2 in tissues, contaminated powder
90	71	2						Th-O2 in tissues, contaminated powder
91	71				2.63			U-Th-O2 in BeO, tissues and powder
92	Long term storage							N/A
93	71	0.1						Residues of U-Th-O2 in pill packs
94	71			0.1				Natural "A.D.U."(unknown), probably contaminated
95	Long term storage							N/A
96	Long term storage							N/A
97	Long term storage							N/A
98	Long term storage							N/A
99	72				0.275			Irradiated, enriched, U-Al section
100	72				0.5			U-235 in non-aqueous solution (0.5 L)
101	74			2.55				Machining waste from fuel pellets, coolant, etc
102	Long term storage							N/A
103	75	1.3						Th-oxide powder
104	75	1.14						Th-oxide powder
	SUM	47.75	51.5	21.52	121.8	4.20	6.88	
		Kg	Kg	Kg	g	g	g	

As discussed in the main text, it appears that the SDRs (reported in Appendix F) were used to compile fissile and fertile inventories in the EHM document (which is the source of Appendix E). There are minor inconsistencies between the two tabulations, for example, between the total amounts of U-233 (due to the confusion of the fate of SDR 29 between trenches 47 and 48) and also in the amount of U-235. There was U-235 content in several of the SDR items which were discarded into the treatment plant, which probably ended up in buried sludges at LFBG, but this amount was not accounted for in the EHM inventory. Some SDRs covered multiple items which became separated during subsequent operations (e.g. SDR 68).