7 RADIOACTIVE WASTE STORAGE

The IAEA defines storage as [5.1]:

> *the holding of spent fuel or of radioactive waste in a facility that provides for its containment, with the intention of retrieval*
>
> *Storage is by definition an interim measure, and the term* ***interim storage*** *would therefore be appropriate only to refer to temporary, short-term storage when contrasting with the longer-term fate of waste. Storage as defined above should not be described as interim storage".*

The purpose of this Section is to discuss issues related to radioactive waste storage, not interim storage. It is realized, however, that not all countries follow the IAEA's recently stated definition in a consistent manner. As well, some IAEA publications that were in development or developed prior to reference [5.1] do not use the definition cited above [4.3], [7.1] to [7.3]. Like waste classification (see Section 3), the inconsistent use of terms like storage, interim storage, temporary storage, short-term interim storage, short-term temporary storage, etc. leads to confusion at both the national and international levels as to the purpose of a storage facility.

As with the waste classification issue, in order "*to facilitate communication and information exchange among Member States and to eliminate some of the ambiguity that now exists*", consistent use of terminology is essential, especially in light of the statement in the FOREWORD to this report that "*Only 2% to 3% of the people in Europe thought they were well informed about radioactive waste*". If there is confusion over terms by those who manage radioactive waste, it is little wonder why there is confusion for those not directly involved in the field.

To try to address this issue, the IAEA's Net Enabled Waste Management Database (NEWMDB), see subsection 3.2 and subsection 11.2, uses the definition of storage cited above to collect information about waste storage facilities in IAEA Member States. In addition, the NEWMDB states the following [7.4]:

> *In the NEWMDB, interim storage applies to waste that is being held for a short time while awaiting transfer to an available disposition option. For example, waste being stored in a processing facility awaiting transfer to an available storage or disposal facility would be considered to be in interim storage. If waste is being storage because there is no place to send it, for example, it is being stored because there is no processing or disposal alternative available, the waste would be considered to be in storage, not in interim storage. In general, the NEWMDB considers temporary to imply periods of less than one year.*
>
> *disposition option: used in the NEWMDB to indicate option(s) for routing waste to a waste management facility, as follows:*
> *<u>origin => destination(s)</u>*
> *generator => processing, storage, disposal*
> *processing => storage, disposal*
> *storage => processing, disposal*

The intent of the NEWMDB is to collect clear and unambiguous information. As such, for the collection of information about storage facilities and stored waste in IAEA Member States, the NEWMDB On Line Help [7.5] states the following:

> *3) To avoid possible double accounting, waste that is in storage awaiting transfer to an available disposition option is excluded from the scope of the NEWMDB. Examples are hospitals, universities and research centres carrying out what is often referred to as interim storage prior to transfer of the waste to a central, licensed waste management facility (processing, storage or disposal). Waste that is being held because there is no disposition option would be included in the NEWMDB. For example, when this Help file was written, "greater than class C" waste was being held at reactor sites in the USA because a repository for this waste was unavailable. The waste at the reactors would be reportable to the NEWMDB.*
>
> *Waste awaiting treatment and/or conditioning at processing facilities is excluded from the NEWMDB since, typically, there is an available disposition option (storage and/or disposal) after processing.*
>
> *(4) High Level Waste (HLW) at processing facilities should be reported by the facility holding the waste as of the Reporting Year for the NEWMDB. While this waste could be considered to be in interim storage (since a disposition option is available, per point 3), HLW should be reported to avoid missing significant waste in any given reporting cycle.*

As indicated in Figure 2-1, the IAEA Safety Fundamentals document [2.2] considers the storage of radioactive waste as one of the steps in predisposal waste management. The Safety Fundamentals document also states "*Disposal is the final step in the radioactive waste management system.*". However, as indicated on Page 15, "*Currently, there is an international debate about whether or not disposal is the end point for waste management - some have proposed alternatives such as long-term storage.*" This is yet another potential source of confusion at the national and international levels as long-term storage is used by some to indicate storage on the order of 100 years prior to disposal while others use long-term storage to indicate an alternative to disposal (i.e., indefinite storage).

One important fact is clear - there is an increasing reliance on waste storage due to limited, worldwide progress in implementing waste disposal. This issue was discussed in detail in subsection 7.2 of the previous issue of this Status and Trends report. Some reasons for implementing long-term storage as a precursor to disposal (not indefinite storage) are:

- Some recently generated radioactive waste can release large quantities of heat and radiation. This is typically high activity LILW (such as large Co-60 sources), HLW and spent fuel declared to be waste. The decay of radioactivity and heat is very large during the first decades of storage (see Figure 7-1), therefore, significant reductions in handling risk can be achieved by storing these wastes for several decades as a minimum;
- Spent fuel might become an energy resource in future, therefore, there is merit in deferring a decision on declaring spent fuel as waste and disposing of it;
- The time needed for qualifying a deep geological site for HLW and/or spent fuel disposal and to construct a repository is very long, as such, there may be a simple necessity to store these wastes for decades;

- Deferring disposal can take advantage of research in progress that can lead to "as reversible as possible" disposal solutions; and
- Deferring disposal may be based on doubts on the capability of current science to ensure adequate safety levels over the required time span (hundreds of thousands of years).

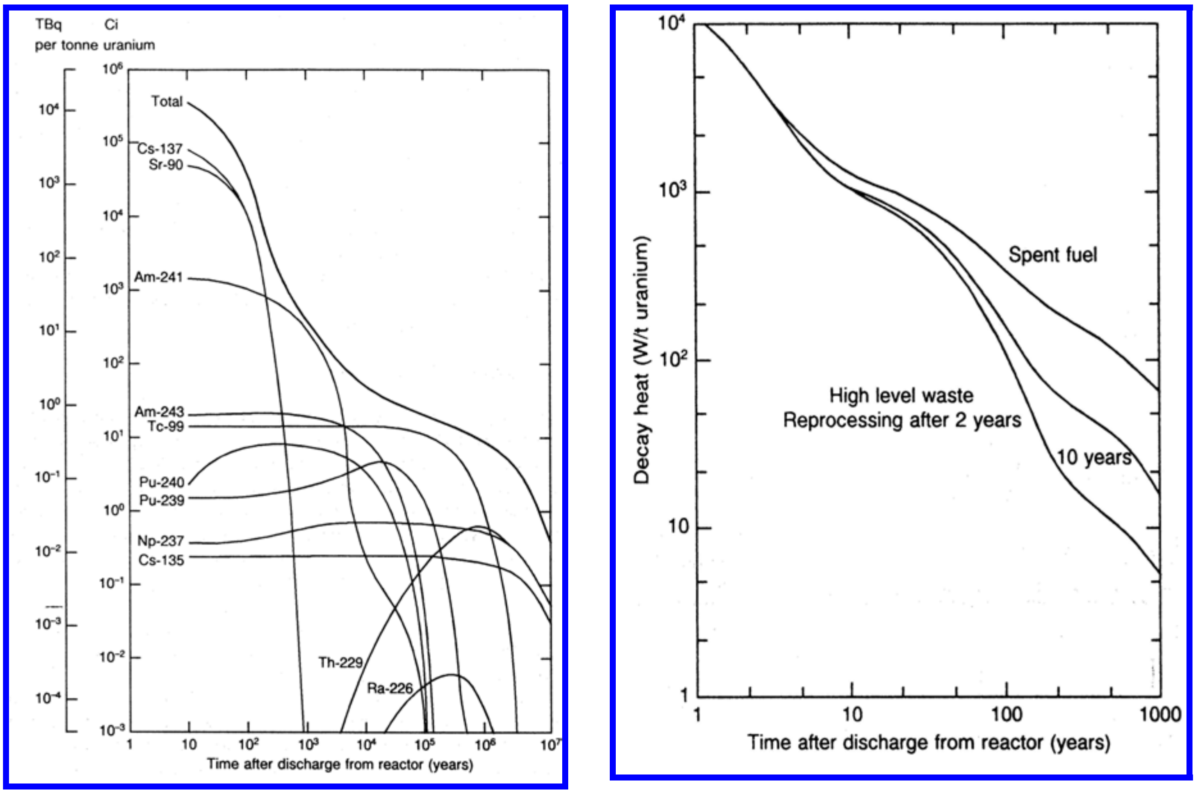


Figure 7-1: Reduction in radioactivity and decay heat over time

Delays or deferral of disposal result in storage times longer than had been originally planned by waste management organizations. This has resulted in the implementation of additional storage facilities. As an example, The Netherlands has declared storage of radioactive waste as the official radioactive waste management policy in a position paper that was released in 1984 [7.6]. Since that time, a national storage facility for LILW was built and taken into operation in 1992 by the Central Organization for Radioactive Waste (COVRA). A facility for HLW, HABOG, is now under construction on the same site in Vlissingen (see the box on the next page). The design of both facilities is such that storage of the waste can be continued for at least a period of 100 years without major structural adjustments.

In the context of the increasing times for the storage of radioactive waste, the IAEA is preparing a Safety Guide [7.7]. However, one of the conclusions from the conference on the safety of radioactive waste management in Córdoba, Spain in 2000 [7.8] was that indefinite storage of radioactive waste is not a sustainable practice and offers no solution for the future. Instead, storage is merely one phase in the integrated management of radioactive waste that concludes with disposal. This conclusion is revisited in subsection 8.2.

Although the monitored, retrievable and passively safe storage of waste may be achievable for decades, the Córdoba conference concluded that progress must be made towards developing disposal. Storage must not be used as an open-ended "wait and see" option – parallel with storage, countries should develop disposal plans. Participants at the Córdoba conference further noted that long-term storage is not a simple or a cheap process, it will require institutional control by a body with the necessary knowledge, expertise and financial resources. Investigations have indicated that storage can be continued safely for many decades, provided that control is maintained. However, even if technological advances were to make safe storage feasible for longer terms, the issues concerning the maintenance of institutional control could be a limiting factor.

Mounting one of the storage vaults for vitrified HLW in the HABOG

"Progress with construction of the HABOG storage facility"

The construction of the HABOG facility for storage of vitrified high level waste at the COVRA site is progressing steadily without major delays. The concrete structure of the building has assumed its final shape, the stainless steel storage vaults (see adjoining figure) have been positioned and the thick concrete roof on the building has been cast in the summer of 2001. The major efforts are now aimed at finishing the interior of the building and the installation of the electrical and mechanical equipment. It is expected that the construction of HABOG will be finished early 2003. The rest of that year is reserved for testing the proper operation of all equipment and amending any deficiencies that may arise. The facility is scheduled to enter into operation in 2004 for accepting and emplacing the first batch of canisters of vitrified waste in the storage vaults.

Source: Central Organization for Radioactive Waste (COVRA), the Netherlands

"State new owner of COVRA"

On 15 April 2002 an agreement was signed between the shareholders in COVRA in which all shares were transferred to the State. With this transaction the ownership of COVRA resides now for 100% with the government of the Netherlands. The former shareholders, the utilities EPZ (operator of the NPP Borssele) and GKN (operator of the NPP Dodewaard, now under decommissioning), settled their obligations with respect to present and future costs for the management of HLW with a down payment amounting to a total of € 56 million. This sum includes long term storage of vitrified high level waste, the operation of the storage building HABOG, as well as final disposal in due time. The third retiring shareholder, the research organisation ECN, will settle its share in the obligations on an annual basis. Reasons underlying this change of ownership include the liberalisation of the electricity market, which became effective in the Netherlands as of 1 January 2001 and the government's decision to phase out of nuclear energy for electricity production by the envisaged closure of the NPP Borssele as of 1-1-2004.

Source: COVRA, the Netherlands

Delays or deferment of disposal mean that stockpiles of spent fuel and radioactive waste that require safe and efficient management are accumulating. This is a key issue in the sustainable utilization of nuclear energy (see subsection 2.1, "Topical Issue - Update: Sustainable Development and Radioactive Waste"). Many storage facilities around the world have had to expand their existing capacities at reactor sites or provide additional storage space to accommodate arisings.

The next two subsections discuss specific aspects of spent fuel and HLW (from reprocessing) storage. Also included is a discussion of conditioning in support of storage.

7.1 Storage of Spent Fuel

Table 7-I provides some perspective of the issue of spent fuel storage and its future evolution [7.9].

Table 7-I: Predictions of Spent Fuel Stored in World Regions (kilo tonnes of heavy metal)

Region	1997	2005	2010	2015
Western Europe	34.2	40.1	38.9	36.4
Asia & Africa	12.5	27.6	38.6	50.2
Eastern Europe	18.0	31.1	39.4	47.9
North and South America	64.6	91.3	108.4	125.9
Total World	129.3	190.1	225.3	260.4

Spent fuel assemblies are being stored in water-filled pools (also called ponds) at reactor sites (AR) or alternatively in dedicated dry storage facilities in storage casks or vaults away from reactors (AFR). Often a facility for dry storage of fuel elements will be operated on a national or regional basis to benefit from economics of scale.

7.1.1 Wet Storage of Spent Fuel

With the exception of Magnox fuel assemblies, spent fuel from nuclear power reactors can be safely stored in water filled pools for a long time. Substantial experience with storage in pools has been obtained over several decades. Various documents have been published on the design, operation and safety assessment of these facilities [7.10] to [7.12].

The main safety concerns are those to do with containment, sub-criticality, heat removal and radiation shielding. A robust design, adequate redundancy of supply systems and site specific provisions against external events are common practice. The effect of a complete loss of cooling water has been identified as the most severe accident scenario. Other activities in the storage pool may cause mechanical damage to storage racks or to the pool in case of handling failures. However, only a few incidents have occurred, with only low or insignificant safety relevance.

The trend in recent years towards increased burnup, with correspondingly higher initial uranium enrichment of the fuel assemblies, requires a reconsideration of the criticality safety concept.

7.1.2 Dry Storage of Spent Fuel

Various concepts for the storage of spent fuel under dry conditions have been developed and implemented. Details are available in reference [7.9]

Dry storage seems to be attractive not only from an economic standpoint but also from its significant positive safety attributes:

- Inherently safe cooling by natural air convection,
- Sub-criticality without moderation of the fuel,
- No necessity for permanent water treatment and no discharges of radioactive

substances into the environment, and

- Robustness against external impact and strong shielding by solid materials.

Experience with dry storage is growing and very positive. Dry storage - especially for aged fuel - has fully reached technical maturity. Dry storage is also used for HLW.

Figure 7-2: MACSTOR dry storage facility (Canada)

7.1.3 Conditioning of Spent Fuel

The conditioning and packaging of spent fuel are part of a consistent strategy for storage and disposal. These steps have to be in line with the conditions for storage and for the repository, in order to avoid unnecessary handling and repackaging actions. Technically, most of these conditioning steps are relatively simple: the fuel assemblies can be directly inserted into canisters or are disassembled, consolidated and closely packaged in canisters. Some conditioning concepts also include filling the packages with a backfill material in order to increase the resistance against external pressure in the repository. Technically, these concepts seem to be feasible, without significant safety problems, using a hot cell facility. Practical experience, however, is lacking, because conditioning facilities are not yet in operation.

7.2 Reprocessing Waste

The predisposal management of liquid HLW from reprocessing consists of two main steps: storage of these liquids in stainless steel tanks and subsequent vitrification and storage of the resultant glass blocks under dry conditions in containers or concrete vaults. The reprocessing scheme has been adjusted in such a way that sludges from feed clarification can now be routed via the liquid HLW procedure and followed by vitrification. It has, however, to be noted that considerable quantities of LILW residues from previous reprocessing activities are still being stored, calling for separate treatment.

In general, significant progress has been made at the reprocessing facilities in reducing the waste volume arisings per tonne of reprocessed nuclear fuel. New facilities will start operation soon that will attain further volume reduction [7.13].

7.2.1 Storage of Liquid HLW

The storage of liquid HLW remains a major safety issue of waste management at reprocessing facilities owing to the very high radioactive inventory of storage tanks, in the order of 10^7 or 10^8 TBq [7.14]. The liquid HLW concentrates have to be permanently cooled by active cooling systems and ventilated to prevent the possibly dangerous accumulation of radiolytic hydrogen and decomposition products. Other safety concerns are the accumulation of sludges, calling for permanent agitation of the solutions, the possible corrosion of cooling coils, ventilation equipment or the tanks, and also the considerable problems of cleaning and eventually dismantling these tanks.

Especially at sites of military reprocessing, majors remediation problems continue to exist. Programmes to reduce these safety hazards, especially at Hanford and Mayak, must be given top priority. Corrective actions are also necessary and are under way at commercial reprocessing sites to empty the tanks and solidify the solutions [7.15]. Modern reprocessing strategies have been established to reduce the need for liquid HLW storage to small volumes and for shorter time periods with timely solidification of the wastes. Vitrification, therefore, has become an integral part of reprocessing operations. Also, for smaller pilot plants, the treatment of liquid HLW residues is important, otherwise decommissioning and dismantling are not feasible. Examples of these activities are the vitrification of liquid wastes from the EUROCHEMIC plant in the PAMELA facility and the recently constructed vitrification facility at Karlsruhe to solidify liquid from the WAK reprocessing plant.

7.2.2 Conditioning (Vitrification) of Liquid HLW

Experience in several countries shows that the vitrification of liquid HLW has reached technical maturity and has a very good safety performance record. This is true for different vitrification techniques: the two step process with calcination to oxide and subsequent vitrification in a metal smelter, as is used in France and the United Kingdom, or the vitrification procedure using large ceramic smelters, as is used in Belgium, Germany, the United States of America, the Russian Federation and Japan.

By autumn 1998, the two vitrification facilities at La Hague had produced more than 6 200 glass canisters, corresponding to more than 5 500 m^3 of liquid HLW [7.16].

The operation of these facilities also shows that off-gas cleaning is very effective; no major modifications having had to be applied. At Sellafield, however, the vitrification lines did not reach the expected annual throughput and a third, additional line had to be installed. Some problems with handling tools and contaminated used equipment parts and smelter scrap material have to be solved. A consistent management scheme for dealing with these residues should be established. Specific safety issues have to be considered for the solidification of some old wastes from the military sector. The presence of sodium, aluminium, organics or fissile material has to be taken into account. An adaptation of the vitrification technique for the disposal of excess weapon grade plutonium is under development in the USA (can-in canister process).

Table 7-II, extracted from Reference [7.3], gives an overview of the type of information that has been compiled by the IAEA for storage facilities for radioactive waste (while the following table indicates only European countries, Reference [7.3] provides information for many other IAEA Member States).

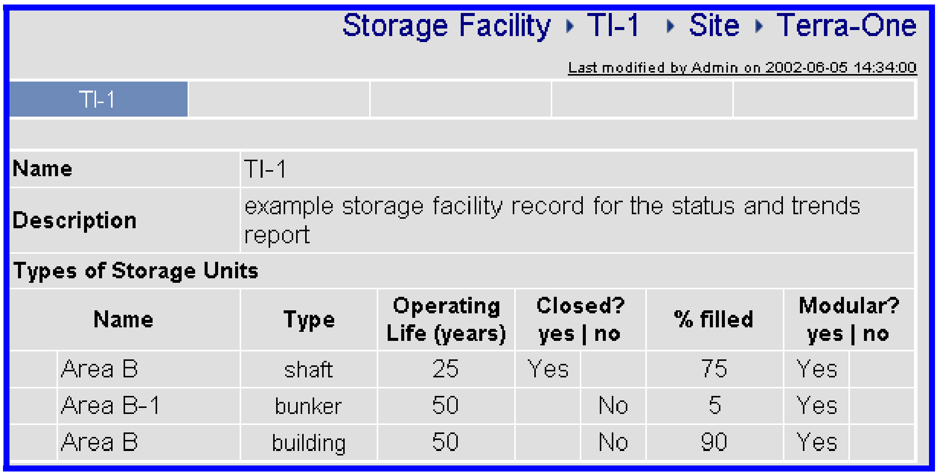
7.3 Compilation of Radioactive Waste Storage Facilities

The IAEA's newly implemented Net Enabled Waste Management Database (NEWMDB, see Section 11.2) is being used to collect information about radioactive waste storage facilities in IAEA Member States. Two types of information are being collected: (a) attributes of the facilities themselves, see Figure 7-3, and (b) the total inventory of radioactive waste in all facilities at a waste management site, see Figure 7-4. Inventories are reported according to the waste classification schemes used by individual Member States, see subsection 11.2.

The intent is for the NEWMDB to become the authoritative, up-to-date source of information about waste storage facilities and stored wastes inventories in IAEA Member States.

Table 7-II: Examples of Storage Systems in Some European Countries
(extracted from Reference [7.3], published in 1998)

Country/location/ Name of Facility	Type of Storage	Type of Building	Waste	Package	Capacity
Austria	Engineered	Warehouse	Cemented LILW	200 L drums	3000 m^3
Belgium/Mol/Dessel	Engineered	Warehouse	LILW, low Contact dose rate	28 L cans, 200 L drums	4500 m^3
Belgium/Olen	Area	--	^{226}Ra contaminated LL ore waste		
Belgium/Mol	Area		LILW, low Contact dose rate, NIW combustible	1 m^3 SS container	500 m^3
Belgium/Mol	Engineered	Shelf piling	LILW, liquid NIW	30 L PE bottles	120 m^3
Belgium/Mol	Engineered	Concrete floor with sand walls and roof, underground steel tubes	LILW, high Contact dose rate. HLW, non-Immobilized	30 L MS boxes, SS 60 L boxes, PE boxes	
Belgium/Dessel	Engineered	Concrete bunkers (80cm wall thickness)	LILW, high contact dose rate, cemented hulls and end fitting pieces, bituminized sludges from COGEMA	1200 L asbestos/cement containers, 200L SS drums	732 m^3 (270 containers and 2042 drums)
Belgium/Dessel	Engineered	Concrete bunkers (80cm wall thickness)	LILW, high contact dose rate, immobilized in bitumen, concrete, asbestos/cement	700 L asbestos/cement containers, 200 L SS drums, 400 L painted drums	4556 m^3 (18393 drums)
France/La Hague (R7)	Engineered	Heavily shielded concrete vaults (5 vaults)	HLW glass	150 L SS canisters	4500 canisters
France/La Hague (EDS)	Engineered	6 cells	Cemented hulls and end fittings, technological waste	1200 L SS containers, asbestos/cement containers, fibre concrete containers	2484 drums, 1184 containers, 4400 containers
France/La Hague (extension of EDS facility – D/E EDS)	Engineered	Modular concept (2 cells planned)	Technological waste, compacted hulls and end fittings	150 L SS canisters	20000 canisters



Storage Facility ▸ TI-1 ▸ Site ▸ Terra-One

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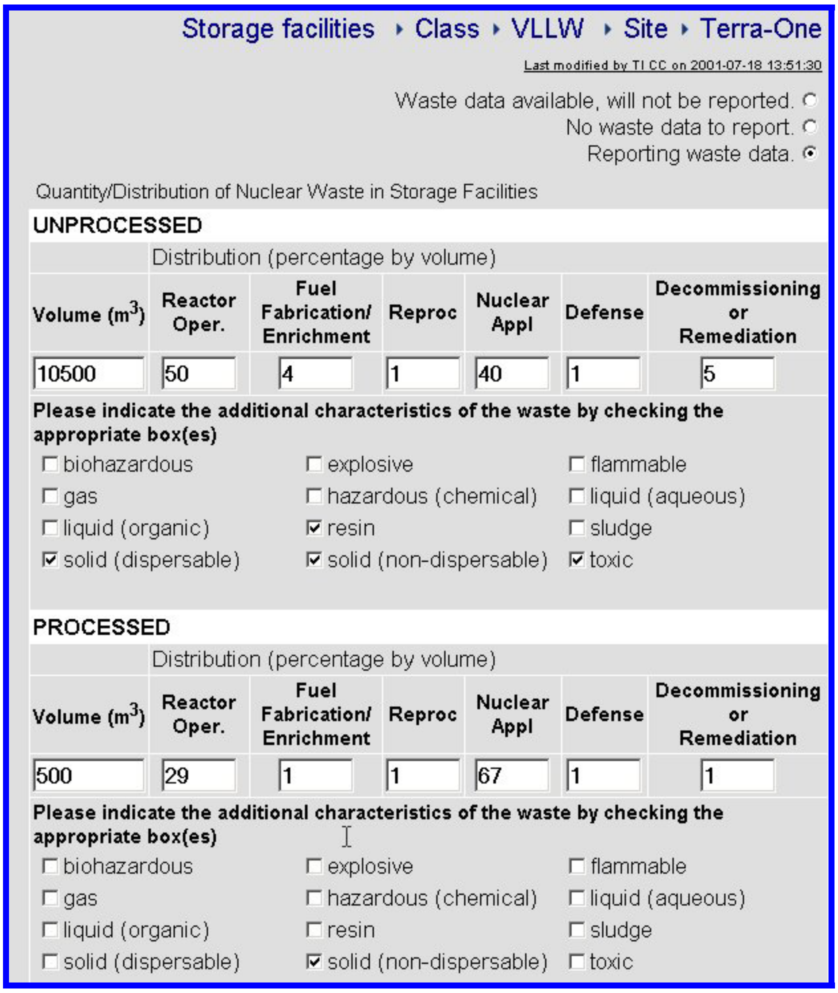
TI-1

Name	TI-1
Description	example storage facility record for the status and trends report

Types of Storage Units

Name	Type	Operating Life (years)	Closed? yes | no		% filled	Modular? yes | no	
Area B	shaft	25	Yes		75	Yes	
Area B-1	bunker	50		No	5	Yes	
Area B	building	50		No	90	Yes	

Figure 7-3: Facility Attributes Screen (NEWMDB)



Storage facilities ▸ Class ▸ VLLW ▸ Site ▸ Terra-One

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Waste data available, will not be reported. ○
No waste data to report. ○
Reporting waste data. ◉

Quantity/Distribution of Nuclear Waste in Storage Facilities

UNPROCESSED

	Distribution (percentage by volume)					
Volume (m^3)	**Reactor Oper.**	**Fuel Fabrication/ Enrichment**	**Reproc**	**Nuclear Appl**	**Defense**	**Decommissioning or Remediation**
10500	50	4	1	40	1	5

Please indicate the additional characteristics of the waste by checking the appropriate box(es)

☐ biohazardous	☐ explosive	☐ flammable
☐ gas	☐ hazardous (chemical)	☐ liquid (aqueous)
☐ liquid (organic)	☑ resin	☐ sludge
☑ solid (dispersable)	☑ solid (non-dispersable)	☑ toxic

PROCESSED

	Distribution (percentage by volume)					
Volume (m^3)	**Reactor Oper.**	**Fuel Fabrication/ Enrichment**	**Reproc**	**Nuclear Appl**	**Defense**	**Decommissioning or Remediation**
500	29	1	1	67	1	1

Please indicate the additional characteristics of the waste by checking the appropriate box(es)

☐ biohazardous	☐ explosive	☐ flammable
☐ gas	☐ hazardous (chemical)	☐ liquid (aqueous)
☐ liquid (organic)	☐ resin	☐ sludge
☐ solid (dispersable)	☑ solid (non-dispersable)	☐ toxic

Figure 7-4: Waste Inventory Input Screen for Storage Facilities (NEWMDB)

References to Section 7

7.1 "Handling and Processing of Radioactive Waste from Nuclear Applications", International Atomic Energy Agency Technical Reports Series No. 402, 2001.

7.2 "Status and Trends in Spent Fuel Reprocessing", International Atomic Energy Agency Technical Document, IAEA-TECDOC-1103, 1999.

7.3 "Interim Storage of Radioactive Waste Packages", International Atomic Energy Agency Technical Reports Series, IAEA-TR-390, IAEA, Vienna, 1998.

7.4 On Line Glossary for the NEWMDB: http://www-newmdb.iaea.org/glossary.asp

7.5 On Line Help for the NEWMDB, limitations with regards to storage facilities http://www-newmdb.iaea.org/showhelp.asp?Topic=6-4-102

7.6 Radioactive Waste Policy in the Netherlands, Second Chamber, session 1983-1984, 18343, No. 2.

7.7 "Storage of Radioactive Waste", International Atomic Energy Agency draft Safety Guide (DS292), in preparation.

7.8 L. Williams, Proceedings of the International Conference on Safety of Radioactive Waste Management, Córdoba, Spain, 13 - 17 March 2000, International Atomic Energy Agency publication STI/PUB/1094, August 2000.

7.9 "Storage of Spent Fuel from Power Reactors", International Atomic Energy Agency Technical Document, IAEA-TECDOC-1089, 1999.

7.10 "Design of Spent Fuel Storage Facilities", International Atomic Energy Agency Safety Series No. 116, IAEA, Vienna, 1994.

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7.13 W. Thomas, Proceedings of the International Conference on Safety of Radioactive Waste Management, Córdoba, Spain, 13 - 17 March 2000, International Atomic Energy Agency publication STI/PUB/1094, August 2000.

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7.16 J.L. Desvaux et al. "The R7/T7 Vitrification in La Hague : Ten Years of Operation", Waste Management 99 Symposium, Tucson, Arizona, USA, March 1999.