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Experiences of Storage of Radioactive Waste Packages in the Nordic Countries

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April 2001

Abstract

The present report includes results from a study on intermediate storage of radioactive waste packages in the Nordic countries. Principles for intermediate storage in Denmark, Finland, Norway and Sweden are presented. Recommendations are given regarding different intermediate storage options and also regarding control and supervision.

The disposal of drums at Kjeller in Norway has also been included in the report. This is an example of an intended (and correctly licensed) disposal facility turned into what in practice has become a storage system.

Key words

Intermediate storage, radioactive waste, waste disposal, radiation protection, discharge control

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1 Introduction

Intermediate storage of radioactive waste and waste packages is used routinely as a step in radioactive waste management.

One purpose of such storage could be to wait for the decay of relatively short-lived radioisotopes so that the waste can be more easily handled or even declassified for reuse or disposal as inactive material. Such waste is termed “temporary radioactive waste“ in the proposed EU classification system [1]. It will typically occur in connections where single well-defined radioisotopes are used, for example at hospitals or in certain types of research. Storage facilities of this type will not be discussed in the following.

Waste from nuclear research or from the nuclear industry including energy production typically contains many different radioisotopes some of which are long-lived. Looking at requirements for final disposal such waste are conveniently separated into High-Level Waste and Low- and Intermediate Level Waste of two types: LILW-SL and LILW-LL where the Short-Lived waste only contains minor amounts of long-lived radioisotopes such as the α-emitters [1].

Facilities for intermediate storage of spent fuel or high-level waste are not discussed here although such facilities exist in the Nordic countries.

The report primarily describes the experience gained in storing radioactive waste of the LILW-SL and LILW-LL type at Risø, IFE and Studsvik build in Denmark, Norway and Sweden in the late 1950’ties originally as nuclear research centres. These institutes have all played an important role in handling in particular nuclear research waste from their respective countries. The development in Finland has been somewhat different but will also be described.

The concept of radioactive waste was well established when the Nordic research centres were set up, but the practical management of the waste – including principles for storage of the resulting waste units – had to be invented along the road. Some ad hoc technical solutions of pressing problems were therefore sometimes adopted, resulting in the rather varied experience described in the following. This is not a special Nordic phenomenon. Other countries may report similar experiences with their so-called ‘historical’ waste.

Some capacity for interim storage of waste waiting for transfer will always be necessary, but long-term storage is needed when disposal facilities are not available. For LILW-SL the situation is very different in the Nordic countries, where operating disposal facilities are available in Finland, Norway and Sweden, while only some preliminary planning for disposal have been initiated in Denmark. No disposal facilities have so far been constructed for long-lived waste, LILW-LL, but in Finland and Sweden this must find a solution in connection with the requirements of the nuclear power plants. In Norway and Denmark without any nuclear power plants the amount of this type of waste is much less, with very long-term storage as a ‘solution’ possibility.

Whenever the long-term storage is selected as a temporary solution in lack of disposal possibilities the quality of the storage facility is of outmost importance for securing the long-term integrity of the waste units. The present report is a contribution within this field, collecting available information and trying to learn from past errors.

Table 1
Problem areas to be considered for interim storage.

Problem area	**Depending on**
External corrosion	Type of waste container, relative air humidity, temperature variations, and leakage from other containers.
Internal corrosion	Type of waste, conditioning method and waste container quality.
Contamination	Original surface contamination, leaking containers.
Radiation doses	Type of waste, emplacement methods, and maintenance requirements.
Control	Stacking method preventing access to some units. Radiation levels.
Loss of information	Unit numbers, keeping track on positions during rearrangements.
Capacity	Waste production. What to do with off-standard waste units.
Cost	Capacity and actual load. Control specifications. Remediation needs.
Accidents	Handling safety, Fire risk and other accident scenarios
Security	Safeguards requirements, risk of unauthorised access.

When planning for interim storage different problem areas should be considered (see Table 1). Most of these considerations will have some impact on cost and on the manpower needed to operate and supervise the storage facility. A reasonable balance must be found between the efforts required and the potential hazards represented by the waste.

A storage facility for low- and intermediate level radioactive waste will be classified as a nuclear facility or as a part of such a facility. It have to be sited, designed, constructed, licensed and operated according to international agreements, national laws and the conditions set up by the licensing authorities. Building of a large new storage facility may require discussion of an Environmental Impact Statement involving the general public and in particular the local community in the permissions for the planned facility.

2 Principles for intermediate storage in the Nordic Countries

The Nordic countries have experiences from different manners of storage of waste packages with low and intermediate level radioactive waste: in temperature controlled storage buildings, in unheated storage buildings, in rock vaults, in concrete silos, outdoors and also storage as a feature in final disposal. A short description is given of the historical development as well as the presently operated low- and intermediate-level storage facilities.

2.1 Denmark

All radioactive waste generated in Denmark since about 1960 is stored at Risø National Laboratory in various types of intermediate storage facilities. Due to the absence of nuclear power plants the volume of Danish waste is relatively small, in total about 1100 m^3 distribute in less than 6000 units. The nuclear research activities at Risø contribute about 2/3 of the volume (declining in later years to about 50%) while the rest is from other Danish users of radioisotopes: laboratories, hospitals and industry.

Waste units with high external radiation, under safeguard or containing significant amounts of α-emitters are stored at 'Centralvejslageret'. It is an underground concrete block with holes for 30 litre stainless steel containers, standard 210 litre mostly galvanised steel drums, or cellars for larger boxes and other units with contaminated equipment of various types. Originally it was an open-air facility which in 1977 was extended and covered by a building served by an overhead crane. The building is unheated but there has been no reason to use the installed air drying facilities. A further extensions took place in 1984 and some capacity increase was obtained by a small internal reconstruction carried out in 2000.

The stainless steel containers (with bits and pieces from post-irradiation studies of fuel pins) or the large α-contaminated equipment (mostly from decommissioning of the Risø Hot Cells in 1990-93) has never been and can presently not be moved from the facility. Previously the 180 positions intended for 210 litre drums were used as decay store for drums, which were transferred to the low-level handling system when the external radiation got sufficiently low (<5 mSv/h at 1 m distance). However, most of the positions are now occupied by drums with slowly decaying hot cell waste, and the function as decay store is taken over by a shielded area in a heated and ventilated building called 'Tromlelageret'.

The standard waste unit used at Risø for low radiation waste is a 210 litre drum of ordinary steel fitted with a central inner 100 litre steel drum and with the annular space filled with cement mortar. This type has been used for low-level waste since the early sixties, but the first about 300 units – containing evaporator concentrate or solid waste – were store outdoors for some years, resulting in corrosion of the outer drum. From 1966 the waste units were transferred to a modular system build from standard concrete rings as used in sewage systems. Originally the silos were small with room for only 12 drums, stacked in three layers with four in each. Water penetration through the top of the silo proved difficult to prevent. From 1979 to 1988 the use of larger silos with 21 drums and a different type of roof improved the performance of the system. However, due to deterioration of waste units in the small silos it was decided to abolish the system and move the 3418 old drums to a new storage facility. The transfer too place from 1993 to 96. Experience from this operation is detailed in Section 3.2.

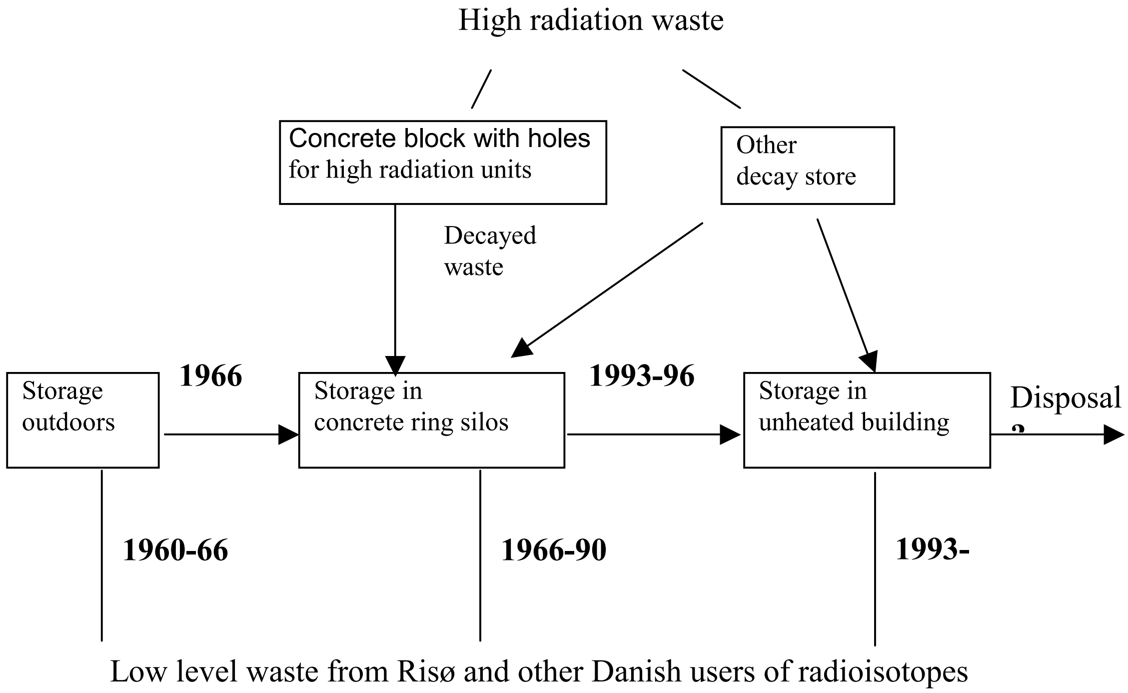

Figure 1
Intermediate storage of waste units at Risø National Laboratory, Denmark.

The new store is a conventional unheated hall construction with the drums stacked in four layers on each side of a central passage. Air drying equipment ensures reasonably low relative humidity thereby eliminating risk of condensation on cool drum surfaces. Recently a problem with internal corrosion in one type of waste units has been observed. Although the activity levels involved are low, this may require some remedial action.

The policy has been to postpone the disposal of Danish radioactive waste until future complete decommissioning of the nuclear research facilities at Risø, notably the DR3 reactor. After closure of this facility in September 1999 comprehensive planning for decommissioning to green field of all the nuclear facilities at Risø was initiated. This includes the former DR2 reactor and the hot cell facilities, which previously had been decommissioned to stage 2. Also the small homogeneous DR1 reactor will be closed. The initial steps in planning for a disposal
facility for the low- and medium level waste units stored at Risø and for the waste produced during decommissioning have also been taken.

A flow sheet of storage development for the radioactive waste units at Risø is shown in Figure 1.

2.2 Finland

In Finland, the main sources of low and intermediate level radioactive waste are the two nuclear power plants (NPP), each having two units. The waste management strategy is based on conditioning, storage and disposal of these wastes at the NPP sites. At both sites, rock cavity disposal facilities are nowadays in operation: the repository was commissioned in 1992 at the Olkiluoto site and in 1998 at the Loviisa site.

At the end of 1999, the accumulated low and intermediate level waste amounted to about 6000 m^3 and two thirds of this amount was in the repositories. The rest was stored at the NPPs.

At the Loviisa NPP, the types of interim storages currently in use are as follows:

- A tank storage for wet wastes, such as ion exchange resins and evaporator residues. Because the NPP has not yet any solidification facility, the amounts of wet wastes were about 1000 m^3 at the end of 1999. The storage consists of eight stainless steel tanks each inside a concrete vault.

- Two storage rooms inside the NPP for mainly low- level maintenance waste packed into 200 l steel drums. These rooms were not originally planned as waste stores and consequently are inconvenient for this purpose, as regards e.g. transfer of waste drums and radiation protection arrangements.

- A rock tunnel in the repository at the depth of about 100 m. During the operational period, the waste packages in the repository are in principle retrievable and the tunnel might be considered a storage system. The waste drums are piled in the rock tunnel as such, without any backfilling material.

At the Olkiluoto NPP, the types of interim storages currently in use are as follows:

- Four storage rooms inside the NPP, two for intermediate level wet wastes solidified in bitumen and two for low-level maintenance wastes. These rooms are purpose-built storages but are nowadays mainly used as buffer storages prior to transfer of the waste packages into the repository. Some large tanks with low level internal contamination are also stored outdoors at the NPP site under cover.

- Two rock silos in the repository at the depth of 60 to 95 meters. During the operational period, the waste packages in the repository are in principle retrievable. The waste packages consist of 200 l drums and steel boxes of 1,4 m^3. These packages are put into concrete boxes of 6 m^3 and transferred into the silos of the repository. No backfilling material is used inside the silos.

The requirements for storage of low and intermediate level nuclear waste are given in STUK Guide YVL 8.3. [2]: Treatment and storage of radioactive waste from a nuclear power plant. According to the Government decision 398/91 [3] the closure of a disposal facility may commence after STUK has approved the closure plan for the facility.

The radioactive waste from small-users of radioisotopes is collected and, as necessary, packed by STUK. The amount of such waste is currently about 40 m^3. Until 1997, these waste packages were stored in a bunker located in the Helsinki area (see Section 3.3). This bunker was originally used as a storage for ammunition and was inconvenient as a storage for radioactive waste (transfer and radiation protection arrangements, temperature variations, and humidity). In 1997, the small-user waste packages were transferred from this bunker into a rock cavity located in the premises of the Olkiluoto repository. These wastes are packed into steel drums (with concrete backfilling as necessary) or in steel boxes. For storage, the waste packages are put into concrete boxes of 6 m^3. Some bulky waste items are put into concrete boxes as such.

The Technical Research Centre has a small research reactor and some laboratory rooms, where radioactive sources are handled. The radioactive waste arising from those practices are packed into steel drums, which are transferred into a purpose-built storage room. The amount of stored waste is currently a few m^3.

2.3 Norway

The facility for waste treatment and storage at the Institute for Energy Technology (IFE) at Kjeller receives low- and intermediate radioactive waste from two Norwegian research reactors, radioisotope production and from external users of radiation sources. Liquid waste is solidified prior to storage.

Low- and intermediate radioactive waste has been temporarily stored in two separate buildings at the IFE-Kjeller site. Both buildings provide controlled temperature and humidity (see Section 3.4).

Storage building I is the oldest facility. It is an integral part of the building housing the waste treatment facility. The building was constructed in 1965-1966. The total area for storage is 434 m^2 giving a maximum capacity of 1000 drum equivalents (1 drum equivalent = the cubical space occupied by a standard 210 l drum). In December 1996, 870 drums were stored in the building. Taken into account that some space is required for safe handling of the drums and the limitation of dose rate in adjacent rooms, this was regarded as the maximum filling grade.

A new storage facility, Storage building II, was constructed in 1977-1978. The capacity of Storage building II is 1400 drum equivalents. In December 1996 the storage contained 1000 drums and 100 concrete- and steel containers (270 drum equivalents).

During the spring 1999 transfer of waste drums to the new combined storage and repository for low- and intermediate radioactive waste in Himdalen was started. All waste drums from Storage building I and II are expected to be transferred by the year 2001 as indicated in Figure 2.

In 1970 a total of 1013 drums and 19 other units containing radioactive waste were buried in clay at Kjeller (see Section 3.6). When the drums were buried this method was recommended by the IAEA and in accordance with current international practise. Radiation protection policy has however changed since then. When the Norwegian parliament in 1994 decided to build the combined storage and repository for low- and intermediate level radioactive activity waste at Himdalen it was also stated that the drums should be retrieved and transferred to this new repository. The 230 drums containing plutonium should be placed in the storage part while the other drums should be reconditioned and placed in the repository part.

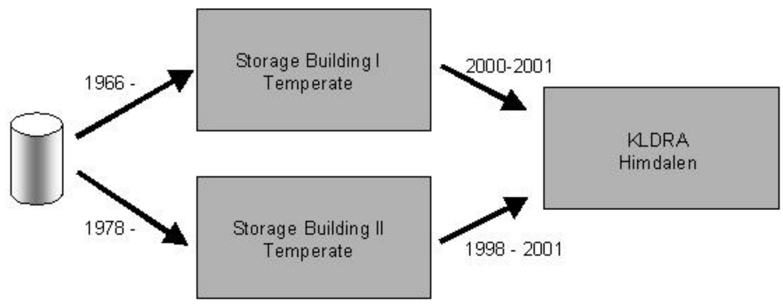

Figure 2
Intermediate storage and initiated disposal at Himdalen of waste units from Institute for Energy Technology, Kjeller, Norway.

2.4 Sweden

The Final Repository for Radioactive Operational Waste, SFR, in Sweden has been in operation since 1988. SFR is used both for operational waste from the nuclear power stations in Sweden and for similar waste from Studsvik. The nuclear power stations in Forsmark, Oskarshamn and Ringhals and also AB SVAFO at Studsvik have in addition shallow land disposal facilities for very low-level short-lived radioactive waste. Some short-term interim storage of waste packages takes place in buildings or in transport containers before transfer to the SFR or to the shallow land disposal facilities. However, part of the waste packages produced at Studsvik, have to be intermediately stored for a longer time since they have not been accepted for final disposal in the SFR.

An unheated storage building owned by AB SVAFO is used for intermediate storage of old steel drums with low-level waste at Studsvik (see Section 3.3). The information about the waste drums in the storage building has in many cases been very limited and many of the drums have also been in bad condition. Projects to both increase the knowledge about the waste in the drums and to recondition the drums are in progress [4]. Some of the drums contain long-lived waste and have to be disposed of in a repository for long-lived low and intermediate level waste (SFL 3-5). This repository is foreseen to be located adjacent to the deep repository for spent encapsulated fuel (SFL 2). A flow sheet for the transfer of old drums is shown in Figure 3.

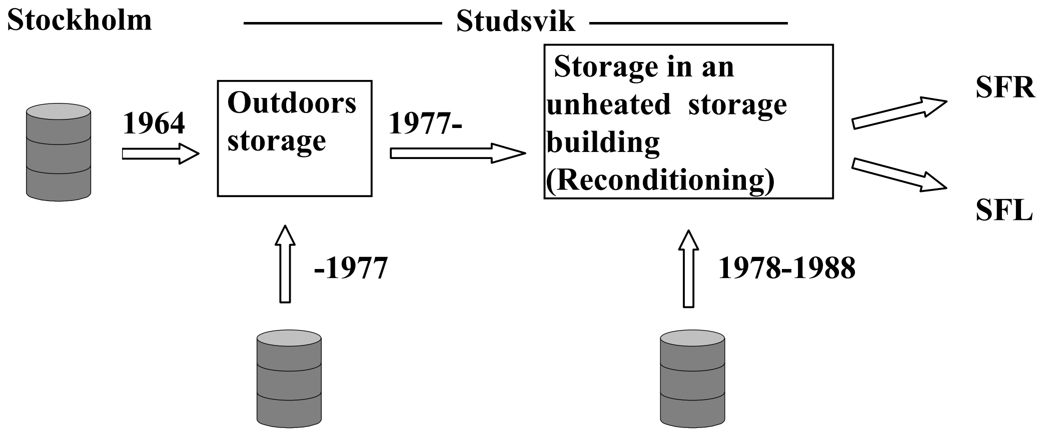

Figure 3
Intermediate storage of old steel drums with low level waste (ashes, refuse and scrap) at Studsvik. The indicated years are approximate. Most of the waste drums produced after 1980 have been transported to the SFR. AB SVAFO owns the remaining drums in the storage building.

An underground purpose build rock facility owned by AB SVAFO is used for intermediate storage of waste packages with intermediate-level radioactive waste at Studsvik (see Section 3.5). Both 200-litre steel drums and concrete containers (outside dimensions 1.2×1.2×1.2 m) are placed in the store. The 200-litre steel drums contain solidified sludge from treatment of liquid waste at Studsvik. The concrete containers have five holes each for 80 litre double-lid drums containing solid waste. The underground store has three separate storage vaults. Two vaults have capacities to store about 900 concrete containers each. The third vault has a capacity to store about 4500 200-litre steel drums. The waste will after the intermediate storage be transferred to SFR or SFL as appropriate, see Figure 4. However, most packages will possibly be transferred to SFL. No use of the rock vaults for final disposal is intended.

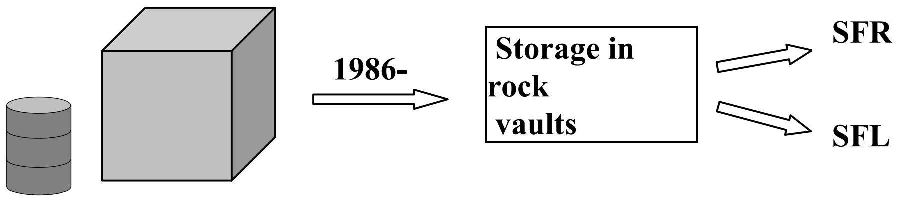

Figure 4
Intermediate storage of steel drums with solidified sludge and concrete containers with intermediate level solid waste at Studsvik.

3 Recommendations regarding intermediate storage

Some general recommendations for design and operation of storage facilities derived from the Nordic experience are presented in the following.

3.1 Outdoors intermediate storage

In wet climates as typical for the Nordic countries longer periods of outdoors intermediate storage of waste drums cannot be recommended. If for any reason the capacity in storage buildings is less than the storage volume required, a solution could be to place the drums in standard freight containers. Studsvik RadWaste AB at Studsvik has positive experience of temporary storage of drums in containers while waiting for transport to the SFR.

Parts of the drums with low-level radioactive waste at Studsvik have been stored outdoors until 1977 when an unheated storage building was built. Although the drums were probably in rather good conditions when they were transferred to the storage building they are now very corroded and lack in same cases marking. Both waste drums from a uranium treatment plant in Stockholm and waste produced at Studsvik were stored outdoors. The drums are now reconditioned and put in outer drums (see Section 3.3).

At Risø a few 100 drums with low-level waste were also stored outside from about 1960 to 1966. This was considered unsatisfactory due to beginning corrosion, and the drums were transferred to the silos system described in the following section.

3.2 Intermediate storage in silos made from concrete rings

Drums with Danish low-level waste were for about 20 years stored in the modular silo system described below. The system was found to be unsatisfactory due to water intrusion and in general high humidity inside the silos. The drums have now been transferred to a new storage facility and reports describing the experience from the transfer are available [5,6].

In the period from 1966 to 1988 the low-level waste units at Risø were stored above ground in silos constructed from standard concrete rings as those used for wells in sewage systems, see Figure 5. Each silo contained 12 or later 21 drums stacked in three layers This modular system was selected to avoid initial investment in a conventional storage building. However, from the mid-seventies it was clear that performance of the system was unsatisfactory. Various improvements were not able to prevent rain from penetrating into some of the 185 small silos. The 58 larger silos behaved better, but also here the inside environment in the silos was humid. Test pumping showed leakage of activity from old units out into the bottom of some of the small silos. Emptying of contaminated water by pumping was carried out systematically every half year. Fortunately the activity levels were quite low and from the point of view of radiation protection there were no problems. Inspection of some of the old silos showed that units containing crystallised but otherwise unconditioned evaporator concentrate were badly corroded and contaminated solution - maybe generated by water uptake into the hygroscopic mixture of salt crystals – was leaking or overflowing from the drums. The cement mortar layer between the two drums in a unit was not made from sulphate resistant cement and was sometimes cracked due to expansive reactions. The about 400 units with unconditioned evaporator concentrate were placed randomly together with units with solid waste in the old silos, and leaking salt solution resulted in bad corrosion also of solid waste units.

A corroded drum with evaporator concentrate from a silo opened for inspection is shown in Figure 6. Later, when the silos were emptied systematically even worse cases were encountered. Some badly corroded units where the concrete was cracked could only be moved with difficulty or broke completely so that the content had to be transferred to new containers. In case of the oldest 10 to 20 silos removal had more the character of digging than of retrieval of individual drums. The original marking on the drum sides and lids were often lost, but in most cases the relevant number could be recovered from the lists of waste units stored in that particular silo. In the small silos the individual position between the 12 units was not recorded, leaving some uncertainty on identification of a minor number of drums.

Of other experiences from emptying the silos it should be mentioned that corrosion of the lid and upper ring is increased when the drum is not completely filled up with cement mortar, because the corrosion protection from the alkaline mortar is lacking in the empty space.

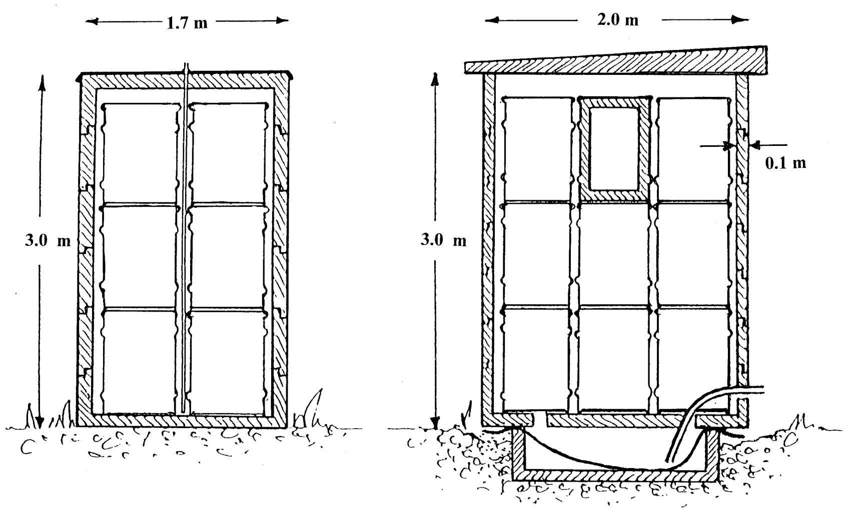

Figure 5
Small and large silos used previously at Risø for low-level waste units. The internal cement mortar layer in one of the drums and tubes for water sampling are also shown.

Figure 6
Corroded drum with evaporator concentrate standing inside one of the small silos opened for inspection 1979.

Some 100 waste units containing bituminised evaporator concentrate in the annular space between the outer and inner drum showed a pronounced ring of corrosion at the level of the interface between the bitumen product and the layer of cement mortar cast on top. The reason is no doubt that moisture from the mortar has dissolved some salt from the bitumen product producing a corrosive salt solution. Many of these units had what was called ‘noses’ i.e. lumps of bituminised material squeezed out from the drum by swelling due to water uptake. For similar reasons at least one unit showed ballooning at the bottom due to pressurisation.

The experience with the Danish silo system illustrates the bad effects of prolonged storage of waste drums in a wet environment. The problems were aggravated by the presence of drums containing unconditioned evaporator concentrate. Bituminised evaporator concentrate is less problematic, but shows in a humid environment the swelling behaviour expected from experimental work [5,6].

In general the possibility of water uptake from high humidity air into hygroscopic waste should be kept in mind.

The silo system cannot be recommended. Also other systems should be carefully evaluated for humidity problems before they are used for long-term intermediate storage.

3.3 Intermediate storage in unheated storage buildings

In general it is the Nordic experience that storage of waste units in unheated and not thermally insulated storage buildings may lead to corrosion of steel drums due to condensation of water on the drum surfaces. Too much air-exchange should be avoided and some type of air-drying equipment may have to be installed to reduce the air-humidity.

At Studsvik in Sweden an unheated storage building owned by AB SVAFO is used for intermediate storage of drums with low-level radioactive waste. The storage building has a 40 m × 42 m concrete floor, an about 0.5 m concrete base, walls with corrugated steel sheeting on a steel framework and a roof with roofing sheets. Totally about 10 000 drums and also some larger odd waste packages have been stored in the facility. The store contains now about 4500 reconditioned drums. In addition about 1500 drums will be placed in the store after reconditioning. The drums were from the beginning placed horizontally in several layers. The reconditioned drums are now placed vertically in four layers with shuttering plywood between each level (see Figure 7). New drums have not been placed in the building since 1988. All new drums with low-level solid waste are now transported to the SFR and long-lived low-level radioactive waste is treated as intermediate level waste and packed in concrete containers with double lid drums. The concrete containers are placed in rock vaults for intermediate storage (se Section 3.5).

The floor has been painted with special oil to avoid earlier problems with quartz dust. Measures have also been taken to solve earlier radon problems. A ventilation plant has been installed and the building has been tightened. However, the ventilation is only in operation when workers are present in the building.

Figure 7
Reconditioned old drums with low-level solid radioactive waste in an unheated storage building at Studsvik.

Figure 8
Standard 210 l drums stacked in the new storage hall at Risø. The picture is from before natural ventilation in the building was diminished among other things by closing the air gabs seen to the left in the corrugated plates of the outer wall. The galvanised light drums in the middle of the stack has relative high radiation but will be shielded by the surrounding black drums.

In Denmark an unheated hall construction has been used for storage of waste drums at Risø since 1996 (see Figure 8). The walls and roof are of aluminium plates and are not thermally insulated. The floor is a thick concrete slap. The drums are stacked by truck in four layers on each side of a central passage as indicated on the picture. Together the drums and the concrete slap represent a large thermal capacity with slow response to external temperature variations. Originally the building was designed with a lot of natural ventilation, but that gave rise to condensation on the cool drum surfaces when the weather changed from a long cool period to warmer conditions with more moisture in the air. The water collected on the lids of drums in the lower layers and took a long time to evaporate. Under such circumstances the orientation of the drums can be important, if the drums had been laying on the side the collection of pools of water would not have been possible. External corrosion was beginning especially around the bottom of the drums. The problem was eliminated by installation of air drying equipment combined with drastic reduction in natural ventilation. However, there is still some risk of condensation in the middle of the stacks.

Another unheated but except for a travelling crane mostly empty hall covering an underground concrete block with steel lined holes and cellars are used at Risø for storage of waste units with high radiation. In this facility the air exchange in the storage positions is slight. An installation for air-drying exists, but need not be used. Regular inspection shows that the storage holes are dry.

A facility with a moderate amount of temperature control is the simple interim storage for radioactive waste used for storage of small-user waste from 1973 until 1997 in Finland (see Figure 9). The storage is located at the Santahamina Island in the Helsinki area. The island is military area and the storage is a partly underground bunker that was earlier used for storing ammunition. The storage was operated by the STUK, which collected and, as necessary, also packed radioactive waste from small-users. The storage had a simple ventilation system and a heating system so that the temperature could be kept slightly over 10 ^{o}C even in wintertime. The waste packages remained in a fairly good condition during their storage time of 24 years at the maximum. A major disadvantage was lack of space complicating the handling of waste packages and causing unnecessary radiation exposure.

3.4 Intermediate storage in heated storage buildings

In Norway there is positive experience with intermediate storage of radioactive waste units in temperature controlled storage buildings at IFE, Kjeller. This form for storage is considered to reduce the risk for degradation of the waste containers and can therefore be recommended.

The temperature in the two IFE storage facilities is controlled by central heating in the winter. Typically, the temperature will be around 20 ºC but may vary from 15 ºC to 25 ºC. The rate of temperature variation is low as the concrete building and the waste act as a heat storage. The waste drums are thus never subject to frost or excessive heat. Both storage facilities have continuous air ventilation. The air stream pass through absolute filters before it is released, reducing risk of release of airborne activity.

The IFE-Kjeller site is located in the inland of the eastern part of Norway. The climate is dry with cold winters and relatively little precipitation. Relative humidity is typically 40-50% in summer and even lower in wintertime. Taken into account that the buildings have stable temperature and continuous ventilation with air with low relative humidity, the risk for condensation on the exterior or hygroscopic uptake of moisture in the content of the drums is small. Experience from the storage is that the containers are kept dry under all circumstances.

Figure 9
Partly underground bunker used 1973-1997 for interim storage of radioactive waste from small-users in Finland.

Figure 10
Intermediate storage in a building with temperature control at the IFE-Kjeller site.

The actual time the waste unit has spent in the storage is an important parameter when considering the merits of the system. The accessible waste containers show no visible sign of degradation. Visual inspection of the surface reveals a smooth, clean surface without sign of corrosion (see Figure 10).

The oldest containers were placed in Storage Building I in 1966, some 33 years ago. These containers are still not available for inspection as access is blocked by later stored drums. When these containers are uncovered they will be subject to a close visual inspection. In addition it is suggested to select some representative drums (5-10) for a more elaborate study. Reports indicate that some few of the older drums suffer from internal surface corrosion. The corrosion is probably due to a poor concrete quality. It is not clear if the corrosion has degraded the drums significantly. Results from air monitoring and contamination control of the drum surfaces indicate that no leakage of radioactivity has taken place.

Doses to personnel operating the stores are recorded using various methods but they cannot be separated from doses from other work in the waste management facility.

3.5 Storage in rock vaults

Sweden has positive experiences of storage of intermediate level radioactive waste units in rock vaults at Studsvik and this type of intermediate storage can be recommended provided the store can be built in a suitable crystalline rock.

The interim store at Studsvik has the following advantages:

- The rock gives good shielding.
- This type of store is not more expensive to build than a storage building for intermediate level waste.
- The temperature in the store is almost constant all over the year without heating (about 13 ^{o}C).
- The inleakage of ground water to the store is low.
- The humidity of the air in the store does not exceed 60 %. A dehumidification equipment is automatically turn on if the humidity increases.
- The store is equipped with a safety ventilation system. This can be used if the air in the store gets contaminated. The exhaust air is then released through a high efficiency filter.

Each waste package with intermediate level waste is transported to the store in a special shield and then taken out from the shield and transferred to a selected place in a concrete compartment (70 m × 16.5 m) by remote handled equipment. The compartment consists of three parts. Drums with solidified sludge are placed in one part (see Figure 11) while concrete containers with solid waste are placed in the two other parts (see Figure 12). A watertight roof over the compartment is inspected regularly. No defects have been observed.

The packages with intermediate level waste can only be inspected by TV-cameras, but some drums with solidified sludge have less radioactive contents and can be handled unshielded. Some of the drums with low radioactivity content showed about one year ago corrosion spots on the drum surfaces. The spots have now been tightened. No other signs of degradation of the waste packages have been observed.

The water from the store is analysed regularly. No activity has been found in the water.

The air-activity in the store is analysed regularly. No air-contamination has been found.

The intermediate store is usually unmanned and the person who perform most of the work in the store has not received any noticeable dose.

Figure 11
Intermediate storage of drums with solidified sludge in a rock vault at Studsvik.

Figure 12
Intermediate storage of concrete containers in a rock vault at Studsvik.

3.6 Storage as a feature in final disposal

In licensing final disposal systems it is getting more and more common to require certain possibilities for retrieval of the waste. The requirement can be for a certain part of the waste – as specified for example for Himdalen in Norway – or it can cover a certain period before the facility, which initially is regarded as a temporary store, is converted into an actual disposal facility.

Carefully planed storage in a facility, which eventually can be turned into a disposal system, is technically a perfectly acceptable option, but the need of remedial actions involving retrieval of old waste from small ad hoc disposal facilities should as far as possible be avoided.

The waste drums buried in a field at IFE, Kjeller, Norway is an example of an intended disposal facility turned into what in practise has become a storage system. When the drums were buried in 1970 this method was recommended by the IAEA and in accordance with current international practise. Radiation protection policy has however changed since then. When the Norwegian parliament in 1994 decided to build a combined storage and repository for low- and intermediate level radioactive activity waste in Himdalen (KLDRA), it was also stated that the drums should be retrieved at transferred to this new repository. The drums containing plutonium should be placed in the storage part while the other drums should be reconditioned and placed in the repository part.

A total of 1013 drums and 19 other units containing radioactive waste were buried in two layers (see Figure 13). The radioactive waste consists of laboratory waste, organic liquid waste absorbed in vermiculite and dried ion exchange resins. Metallic waste is embedded in concrete. For high dose rate waste, the drum is equipped with a lead inner container. The total activity in the repository has been estimated at 2900 GBq (1997-07-01) [7]. The repository contains about 80 GBq plutonium (35 g) and 2.5 GBq uranium (100 kg) from a reprocessing pilot plant [8]. The activities for the most important nuclides are shown in Table 2.

Table 2
Inventory of the near surface repository at IFE-Kjeller.

Nuclide	Half-life (years)	Activity [1)] (GBq)
^{60}Co	5.3	60
^{90}Sr	28	1340
^{137}Cs	30	1360
^{239}Pu	24 000	85
U(nat)	$4.5 \cdot 10^9$	2.6
Other [2)]	-	<100

1) Activity as per 1 July 1997
2) Other nuclides includes ^{3}H, ^{14}C, ^{55}Fe and ^{204}Tl

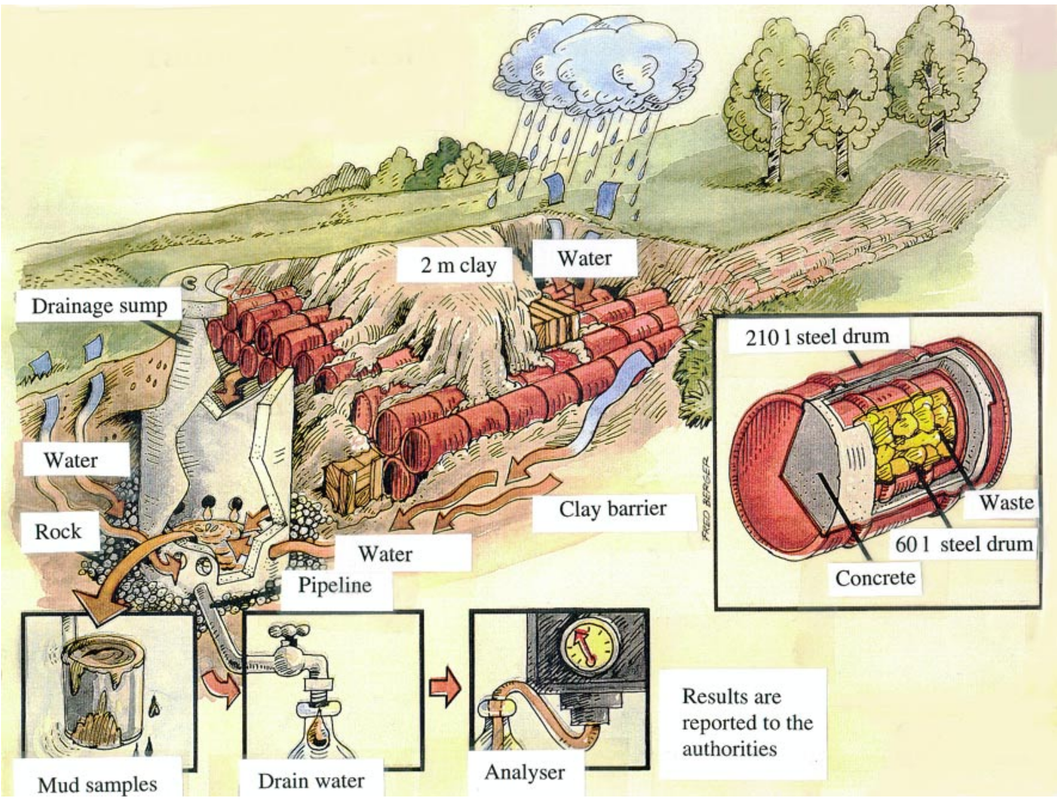

Figure 13
Artistic view of the near surface repository at IFE-Kjeller.

The drums were buried in clay. The reason for choosing clay is that it provides a good barrier against leakage of radioactivity from the field. The water flow through the clay is indeed found to be low. Water running through the field is collected in a drain sump. The water is controlled before it is released. The annual release of radionuclides from the repository is estimated to about 0.5% of the permitted release.

When the drums were buried it was intended that they should be left in the clay and that it should function as a repository. It was calculated that outer drum would have a lifetime of ten years and the concrete would constitute an intact barrier for many years on.

In 1993 representatives from the environmental foundation “Bellona” committed a forced entry to the premises and dug up some drums, one of which were damaged by the mechanical digger. IFE took advantage of the incident and dug up 5 drums for inspection. Following the retrieval of the 5 drums in 1994, a systematic survey of the repository and the drums were initiated. The drums in the upper layer were in remarkable good condition. Drums from the lower layer had however corroded, for some units the outer drum was penetrated.

With two exceptions, no contamination has been detected in the surroundings of the buried drums. One borehole close to the drain sump showed activity concentrations of ^{137}Cs of 10-600 Bq/kg. A trace of ^{137}Cs was also found in another borehole.

The activity levels on rust and clay from the drums range from 1.5 MBq/kg and down [7]. Samples of water taken after retrieval of the drums had a content of ^{137}Cs in the range 1-50 Bq/l and of ^{90}Sr from 1-10 Bq/l. Clay and sludge profiles from the bottom of the repository had activity levels up to 100 kBq/kg in the first 2 cm. Samples from profiles showed that the activity was concentrated in the 2 cm of clay closest to the drum surface.

Prior to retrieving the rest or the drums, a detailed plan for the operation will be worked out. The plan will include radiation protection issues, control and waste treatment of contaminated clay surrounding the drums and reconditioning of the waste drums. The time schedule for the operation has not yet been finalised.

Near surface burial of waste drums should not be recommended for temporary storage of low- or intermediate active radioactive waste. Retrieval of the storage units will require recondition of the containers due to corrosion. The clay surrounding the drums will also constitute a waste problem. Although the activity levels in clay are expected to be low, a considerable amount of material will have to be treated as radioactive waste.

4 Recommendations regarding control and supervision

The storage systems must be constructed, controlled and supervised in such a manner that the safety of the operating personnel and the general public is ensured. These considerations should comprise consequences from normal operations as well as reasonable accident scenarios and prevention of unauthorised removal of the waste materials. The necessary precautions will be very dependent on the waste type.

4.1 Radiation protection

The conditions set up by the national licensing authorities must be followed. This may e.g. involve requirements on admittance, labelling, personal dose control, doserate monitoring, airborne activity monitoring and contamination control.

Figure 14 shows the entrance to a storage area at IFE-Kjeller.

Figure 14
Entrance to a storage area at IFE-Kjeller marked off with a barrier. Before entering the storage area personnel shall use the prescribed clothing. When leaving the area contamination control and hand-wash shall be performed.

4.2 Discharge control

Radioactive waste is normally conditioned into solid form when placed into the storage containers. The storage containers, typically steel drums or various types of concrete containers, are leakage proof. Leakage cannot, however, totally be ruled out. Corrosion and other processes may degrade the barriers and radioisotopes may eventually find their way outside the storage building. An environmental monitoring program at the surroundings of the waste storage facility may therefore be desirable.

The aim of an environmental monitoring program is to survey the releases to the environment in order to ensure that they are kept below the limits for discharge set by the authorities and in general ensure low or no doses to the general population. Discharge to environment may occur through release of gases or aerosols to the atmosphere or leakage of liquids to ground water. Discharge of aerosols can be monitored using a filter system analysed by spectroscopic methods. The risk of releases of significant amounts of radioactive gases is less common and their detection requires special methods. Discharges to ground water may be monitored by analysing the water from the vicinity of the storage using radiochemical and spectroscopic methods.

4.3 Work environment and conventional safety

Conventional safety during work carried out in a storage facility for radioactive waste units must also be considered.

The waste units are heavy and transportation and stacking are carried out using heavy equipment. Conventional accidents involving fall of personnel, equipment or waste units could well be the most risky part of operating such stores. It is important to ensure that the operators are competent, take no chances and know how to use cranes, trucks etc. Stacking of the waste units must occur in such a way that there is no risk of instability. Lighting in the store should be sufficient.

If personnel have to stay in an interim store for longer times conventional work environment aspects must also be regarded. Temperature and draught is one aspect, but the risk of chemicals evaporating from the waste may also have to be considered. Dust is another possibility, and for example the interim storage building for low-level radioactive waste at Studsvik has a concrete floor, which had to be covered by a special paint to decrease the silica concentration in the air.

Safety of the workers is of primary concern, but safety of the installation is also important. The risk is primarily economic because accidental damage may be difficult to repair. This is especially the case for high radiation waste where access to the storage area is limited and operations have to be carried out remotely or using heavy shielding.

4.4 Supervision

During long-time storage it is desirable to be able to supervise or otherwise control the condition of the stored waste units, but possibilities for this must be planned in advance. Direct visual inspection is in some facilities prevented by high radiation levels, but here something may then be done with television cameras as mentioned in Section 3.5.

In other cases the storage system is constructed in such a way that visual inspection is difficult. An example is the silo system described in Section 3.1. In this case control was limited to sampling of the water collecting in the system and by occasional opening of one of the silos.

A commonly encountered problem is that the waste units are stacked in such a manner that the outer ones are preventing direct access to the inner ones. The advantages are savings in space and cost and the fact that outer low level units may serve as shielding for inner ones with higher radiation (see Figure 8), but the disadvantage is that observation of the inner units is prevented. The phenomenon is mentioned in connection with the Norwegian stores and has also been a problem in connection with the new Danish store, where extensive rearrangement of waste drums have been necessary to localise a few leaking containers.

A formal system for reporting results from supervision of waste units and for the general state of the storage facility is advisable.

4.5 Physical protection and security

As a waste also radioactive waste is by definition of no value. However, some types of waste may contain fissionable material and as such it will be under the safegards systems operated by IAEA and Euratom. Physical protection against theft, other diversion or dispersal of such materials will have to be provided according to the rules set up by these organisations.

Radioactive waste units have a certain fascination and may be misused for propaganda purposes. A famous example is the excavation of buried drums carried out by the Bellona environmental group at IFE, Kjeller in 1993. Some protection in form of guards, fences, locks and burglary alarms against incidents of this type is motivated, one reason being to prevent damage to the activists themselves.

Accidental misplacing of large and heavy packages with conditioned radioactive waste is not very probable, but an easily understandable and wear- and corrosion-resistant marking of the units should be considered.

Like for other nuclear facilities the risk from reasonable accident scenarios may have to be considered. Fire is probably the most important. Conditioned waste is often not burnable or at least extremely difficult to ignite, but the presence of unnecessary organic materials inside or near the storage facility should be avoided. Fire risk may speak against situation of storage facilities in immediate connection with buildings having other purposes.

Besides the waste itself information about the waste need to be protected. In connection with improving storage of old radioactive waste a parallel effort concerned with improving the level of information about the waste is often carried through [2.4]. For new as well as old waste units in intermediate storage it is important to ensure the continuing existences of all relevant information. This means that the waste units should be clearly marked at least with numbers (which are not easily lost e.g. by corrosion) and that the associated information specifying contents of radioisotopes etc. is stored securely in suitable data bases until it is needed in connection with disposal of the waste. The special problems associated with long-term availability of such information have been studied in an earlier Nordic study [9].

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Abstract	The present report includes results from a study on intermediate storage of radioactive waste packages in the Nordic countries. Principles for intermediate storage in Denmark, Finland, Norway and Sweden are presented. Recommendations are given regarding different intermediate storage options and also regarding control and supervision. The disposal of drums at Kjeller in Norway has also been included in the report. This is an example of an intended (and correctly licensed) disposal facility turned into what in practice has become a storage system.
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