RAPHAEL

Contract Number: 516508 (FI6O)

DELIVERABLE (D-BF1.1)

Report on the International Regulation as regards HTR/VHTR Waste Management

Author(s): **D.N. Millington (NNC), P. Bros (CEA), A. Sneyers (SCK CEN), F. Cellier (AREVA NP), M.H. Mouliney (COGEMA), H. Brücher (FZJ), T. Abram (Nexia Solutions)**

Reporting period: e.g. 15/04/2005– 28/02/2006

Date of issue of this report : 30/06/2006

Start date of project : **15/04/2005** Duration : **48 Months**

Project co-funded by the European Commission under the Euratom Research and Training Programme on Nuclear Energy within the Sixth Framework Programme (2002-2006)		
Dissemination Level (place an X in the appropriate cell)		
PU	Public	
RE	Restricted to the partners of the RAPHAEL project	
CO	Confidential, only for specific distribution list defined on this document	X

RAPHAEL ***(ReActor for Process heat, Hydrogen And ELectricity generation)***

Distribution list

Person and organisation name and/or group	Comments
G. BRUNA (F ANP)	RAPHAEL-IP Organisation
B. CARLUEC (F ANP)	RAPHAEL-IP Organisation
W. VON LENZA (FZJ)	SP Leader
P. BROS (CEA)	WP Leader
D. GRENECHE (Cogema)	WP Contact
J. FACHINGER (FZJ)	WP Contact
D. MILLINGTON (NNC)	WP Contact , Task Leader
P. VAN ISEGHEM (SCK – CEN)	WP Contact
F. CELLIER (F ANP)	WP Contact
T. ABRAM (BNFL)	WP Contact, Co-Author
D. ROUDIL (CEA)	WP Contact
C. JEGOU (CEA)	WP Contact
A. SNEYERS (SCK – CEN)	Co-Author
M.H. MOULINEY (Cogema)	Co-Author
H. BRÜCHER (FZJ)	Co-Author

ReActor for Process heat, Hydrogen And ELectricity generation (RAPHAEL)		
Sub-project: SP-BF **Work package:** 1	**RAPHAEL document no:** RAPHAEL-0602-D-BF1-1	**Document type:** D=Deliverable ~~/ M=Minute /~~ ~~P=Progress report / S=Support~~
Issued by: NNC (UK) **Internal no.:** 12820/TR/014		**Document status:** ~~Draft/Review/~~Final

Document title

Report on the International Regulation as regards HTR/VHTR Waste Management

Abstract

This document provides a compendium of disposal requirements for HTR-specific wastes across EU member states. The document provides a brief overview of the generic characteristics of HTR waste. It reviews the waste disposal legislation and classification schemes in operation within several EU states and the US. Based on identified common denominators it then derives generic recommendations for disposal requirements.

Revisions

Rev.	Date	Short description	Author	WP Leader	SP Leader	Coordinator
00	28/2/2006	First draft for internal review	D.N. Millington NNC	P. Bros CEA	W. Von Lensa FZJ	E. Bogush F ANP
01	30/6/2006	Final Issue	D.N. Millington NNC D.Millington	P. Bros CEA	W. Von Lensa FZJ	E. Bogush F ANP

CONTENTS

1 Introduction

The generation of waste from the operation of nuclear power plants, and specifically the Very High Temperature Reactor (VHTR) is an issue of major importance with regard to sustainable development, and receives much more attention than in the past when the main emphasis was on the technological development of the reactor systems and high conversion fuel cycles. Waste management and disposal issues have to be incorporated at the outset into the design of future reactors and their associated fuel cycles, and will be a key component of the licensing process in many countries. This issue is specifically identified as a key technology goal of Generation IV nuclear energy systems [1], namely to :

> *"Minimize and manage their nuclear waste and notably reduce the long term stewardship burden in the future, thereby improving protection for the public health and the environment."*

Generation IV reactors, including the VHTR therefore need innovative back-end concepts to improve the retention capabilities of the fuel in final repositories. The fuel must be designed not only from an operational perspective, but also with disposal performance features included.

The objective of the RAPHAEL Sub-Project on the Back-End of the Fuel Cycle (SP-BF) is to study the characteristics and performance of HTR fuel with regard to behaviour in direct geological disposal conditions, and is restricted to consideration of the once-through fuel cycle. As a prerequisite to these studies of disposal performance, it is necessary to obtain an overview of the specifications and requirements for disposal of HTR waste. The purpose of this document is therefore to provide a compendium of disposal requirements for HTR-specific wastes across EU member states. The document provides a brief overview of the generic characteristics of HTR waste and reviews the waste disposal legislation and classification schemes in operation within several EU states and the US. Based on identified common denominators it then derives generic recommendations for disposal requirements.

2 Description of the characteristics of HTR waste streams

This section briefly summarises the generic physical, thermal and radiological characteristics of spent HTR fuel, and reviews the back-end treatment options.

2.1 Physical/Chemical Characteristics

The fuel elements used for previous HTR projects, and proposed for future designs are based upon the generic use of coated fuel particles for the retention of fission products. The coated fuel particle is a microsphere of around 0.8mm diameter. The inner kernel consists of the fuel in the chemical form of either uranium oxide, carbide or a mixture of the two. This is surrounded by a low density carbonaceous buffer layer, followed successively by layers of pyrolytic carbon (PyC), silicon carbide (SiC), and PyC. The resulting microsphere is known as a TRISO coated fuel particle. The surface layer acts as the primary boundary for the retention of fission products, which typically accumulate in the lower density buffer region.

The particles are surrounded by further carbonaceous material and these are pressed together to form either a pebble or a fuel compact. In the case of the prismatic-type HTR, the compacts are inserted into graphite fuel elements. In the longer term, the development of the Generation IV VHTR may consider a reactor with coolant temperatures in excess of 1000 °C with the potential for hydrogen production. Additionally, very high burnups reaching levels of 150-200 GWd/te may be requried. To meet these objectives, Zirconium Carbide coatings are being studied. The comparative performance of SiC and ZrC coated particle fuel is shown in Table 1.

	SiC-coated Fuel Particle	ZrC-coated Fuel Particle
Maximum fuel temperature	≈1600 °C	≈1800 to 2000 °C
Maximum burnup	~100 GWd/t	100 ~ 200 GWd/t

Table 1 – Comparison of Sic and ZrC fuel performance parameters

The back-end options for spent HTR fuel essentially consist of four distinct routes

i. Conditioning and direct disposal of spent fuel blocks.

ii. Separation of fuel compacts from graphite blocks, followed by conditioning and disposal of compacts, and disposal or potential treatment and recycling of block graphite.

iii. As ii, but with additional separation of particles from compacts, followed by conditioning and disposal of particles and of compact graphite, and potential recycling of block graphite.

iv. As ii, but additional removal of particle coatings in order to the access kernels for removal of fission products and potential recycle of uranium, plutonium and/or minor actinides.

This review of disposal specfications is of relevance to options (i) and (ii) above and does not consider the removal of the particles from the compacts and removal of the TRISO coatings, which is outside the scope of RAPHAEL SP-BF. If the ceramic coating of the spent fuel can be demonstated to provide self containment during long term disposal in a repository, the wastes from HTR spent fuel will be considerably easier to deal with than spent fuel wastes from existing reactor designs.

2.2 Thermal Characteristics

In common with spent fuel from LWRs, spent HTR fuel assemblies generate decay heat following discharge from the reactor. This decay heat reduces with time due to radioactive decay, and necessitates active cooling measures following discharge. LWR fuel is stored in cooling water ponds, but for HTR fuel, this will be typically be provided by a dry store with an inert gas environment, such as helium. Typical decay powers for HTR fuel are shown in Table 2 [3]. This shows calculated decay power reduction with time for plutonium-based GT-MHR fuel assemblies, with a core power of 5.9 MW per assembly.

Time	Residual Power (W/Fuel Assembly)
24 h	2925
100 d	515
365 d	185
1000 d	61
5 yr	28
10 yr	18
35 yr	15
100 yr	11
350 yr	7
1000 yr	3
10000 yr	0.3

Table 2 – Decay powers for GT-MHR fuel assembly [3]

2.3 Radiological Characteristics

The masses of actinides and fission products in spent HTR fuel, when normalised to equivalent generated electrical outputs, have been shown to be essentially similar for all designs of HTR and are similar to current LWR designs. Previous studies [2] have compared the inventories of fission products for GT-MHR, THTR and HTR Module against typical LWR fuel of 33 and 45 GWd/te burnup and have identified the major long-lived nuclides after 5 years decay time as shown in Table 3.

	Mass [g/GWye]				
Nuclide	GT-MHR	THTR	HTR Module	LWR-33	LWR-45
C-14	9.70E-02	6.62E+01	5.26E-03	3.40E+00	2.39E+00
Se-79	8.63E+01	2.06E+02	1.56E+02	1.56E+02	1.10E+02
Zr-93	1.01E+04	2.32E+04	2.11E+04	2.35E+04	1.65E+04

Nb-94	2.00E-02	4.40E-03	1.90E-02	8.13E+00	5.72E+00
Tc-99	1.61E+04	2.02E+04	2.25E+04	2.73E+04	1.92E+04
Pd-107	1.10E+04	7.34E+02	4.14E+03	7.91E+03	5.56E+03
Sn-126	1.21E+03	5.28E+02	4.68E+02	7.44E+02	5.23E+02
I-129	5.21E+03	5.70E+03	4.57E+03	5.88E+03	4.14E+03
Cs-135	1.36E+04	8.91E+03	7.30E+03	1.23E+04	8.65E+03

Table 3 – Comparison of fission products in spent HTR and LWR fuel after 5 years cooling

Differences in the ^{14}C levels between THTR and HTR-Module / GT-MHR are due to more favourable nitrogen content assumptions as compared to the experiences at THTR. There are also some differences between LWR and HTR nuclides generation per GWey that can be attributed to the calculation method, for example, the activation products are not taken into account for the GT-MHR system (e.g. Nb-94). In addition, the GT-MHR is loaded with PuO_2 fuel and the THTR with high enriched $(Th,U)O_2$, whereas the LWR system uses low enriched UO2 fuel. Therefore the ratios dealing with the actinides generated in the two systems present significant differences and cannot be compared directly.

3 Review of European and US regulations and disposal strategies

In order to determine the requirements for HTR waste management, it is necessary to understand the requirements for the planned disposal routes. This section reviews the regulatory frameworks, classification schemes and disposal strategies for radioactive wastes in the following countries :

(i) Belgium
(ii) France
(iii) Germany
(iv) UK
(v) USA

The classification schemes are desctribed in detail in this section and are summarised and compared in Table 9. Section 4 then reviews the IAEA guidelines for national classification schemes, and the EU scheme for which this forms the basis.

3.1 Belgium

This section outlines the Belgian institutional and regulatory framework relating to the management of radioactive waste. The role and competence of organisations involved in radioactive waste management in Belgium are briefly reviewed, and the national classification scheme is described.

3.1.1 Waste management regulatory framework and legislation

Similar to other EU Member States with significant civil nuclear power programmes, responsibilities related to the management of radioactive waste in Belgium are shared by different organisations endowed with specific competences. The main organisations involved and interactions between the governmental bodies, the implementing organisation and the nuclear utilities are outlined in Figure 1 [4].

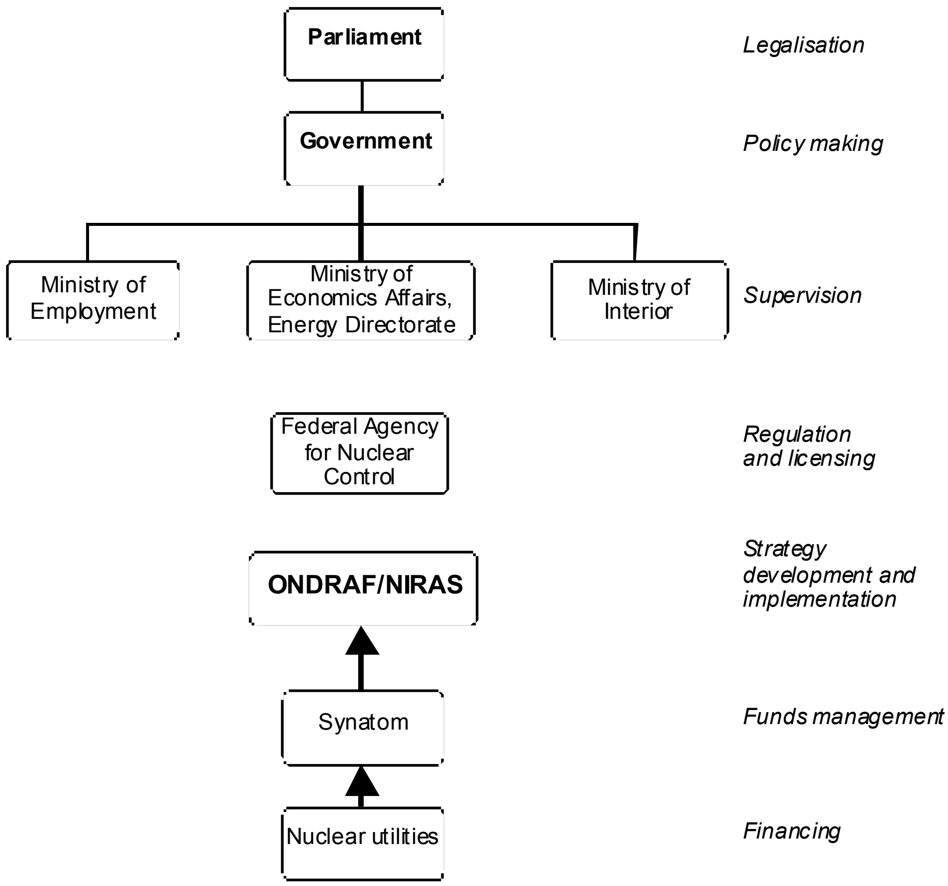


Figure 1 - Overview of the main organisation involved in radioactive waste management in Belgium including their relationships and the interactions between the governmental bodies, the implementing organisation and the nuclear utilities (after reference [4])

3.1.1.1 Overall institutional framework

The **Belgian Federal Government** establishes policies and regulations pertaining to the management of upstream and downstream activities in the nuclear fuel cycle (including issues related to radioactive waste management such as for example the long term options for waste disposal) while the **Belgian Parliament** enacts laws.

Various Ministries supervise various aspects related to the application of radiation. The **Ministry of Employment** is the competent authority concerning the supervision of technical safety in connection with nuclear applications and activities. The **Ministry of the Interior** takes charge of nuclear safety. The **Ministry of Economic Affairs** (Energy Directorate) supervises the Belgian Agency for Radioactive Waste and Fissile Materials (NIRAS/ONDRAF) and the Belgian Nuclear Research Centre SCK•CEN.

The Belgian radioactive waste management agency **NIRAS/ONDRAF** is in charge of the management of radioactive waste in Belgium including the establishment and the maintenance of waste inventories, certain aspects related to the transport of radioactive waste, the treatment, the conditioning the storage and the long term management of radioactive wastes as well as final disposition. Financial resources required for the implementation of the long-term solutions for the management of radioactive wastes are collected into a special fund known as the *Fund for the financing of long-term missions* or the *Long-Term Fund*. This fund has been established under Article 16 of the Royal Decree of 30 March 1981 [5] and is administered by NIRAS/ONDRAF. NIRAS/ONDRAF is the owner of an industrial subsidiary, **Belgoprocess**, which operates facilities for the treatment, the conditioning and the storage of radioactive waste on its site in Dessel.

The **Federal Agency for Nuclear Control (FANC)** is the Belgian safety authority in charge of the surveillance of all nuclear activities. As the competent Belgian safety authority, the FANC is responsible for - among others - the issuing of licenses for the transport of radioactive materials and the authorisation and issuing of licenses concerning the import, the export and the transit of radioactive wastes and the construction and operation of nuclear facilities.

SYNATOM[1] is the Belgian Company for Nuclear Fuels, established in 1969. SYNATOM is responsible for the supply of nuclear fuels and the management of irradiated nuclear fuels from Belgian nuclear utilities located at the Doel and the Tihange sites. In its capacity as legal owner of the spent fuel, SYNATOM provides financial resources required for the management of the radioactives wastes resulting from the operation of its nuclear facilities and power plants and has concluded reprocessing contracts with COGEMA. The Belgian State holds a share with special rights in SYNATOM.

[1] SYNATOM is the Belgian Company for Nuclear Fuels, established in 1969. SYNATOM is a subsidiary from Suez-Tractebel and is in charge of the supply of nuclear fuels and the management of irradiated fuels from Belgian nuclear power plants. In particular, responsibilities of SYNATOM include uranium supply, conversion and enrichment, spent fuel interim storage and conditioning, spent fuel reprocessing. Through a golden share, the Belgian federal government has a veto right to any decision of Synatom's board. On 31 October 2003, TRACTEBEL SA merged with SOCIETE GENERALE DE BELGIQUE SA. The name of the company created as a result of the merger is **SUEZ-TRACTEBEL** SA. SUEZ-TRACTEBEL is a wholly owned subsidiary of SUEZ. **ELECTRABEL** is part of SUEZ-TRACTEBEL and is the private-owned company operating the seven PWR power reactors in Belgium.

3.1.1.2 The Belgian Safety Authority FANC

The **Federal Agency for Nuclear Control (FANC)** is the Belgian safety authority in charge of the surveillance of all nuclear activities. The statute, the missions and the competences of the FANC have been laid down in the Law of 15 April 1994 [6] and the Royal Decree of 20 July 2001 (RD-2001) [7]. The FANC has become operational on September, 1st 2001. By the provision of Article 2 of the Law of 15 April 1994, the FANC is a public organisation with legal personality. The FANC falls under the tutorship of the Federal Minister of Internal Affairs.

3.1.1.3 Establishment of the FANC

The FANC integrates the activities that were formerly performed by the 'Service de Sûreté Technique des Installations Nucléaires' (SSTIN; the Service for technical safety of nuclear installations) and the 'Service de Protection contre les Radiations Ionisantes' (SPRI; the Service for the protection against ionising radiations). The staff of the FANC is composed of specialised personnel of the SSTIN and SPRI services that has been integrated in the FANC as well as of personnel that has been recruited by the FANC. At present, the work force of the FANC includes approximately 120 staff members of which more than 60 percent holding a university degree.

3.1.1.4 Competences and responsibilities of the FANC

As the regulatory body, the FANC is a public organisation endowed with a broad range of competences. The FANC is responsible for the control and the supervision of verification activities related to ionising radiation on the Belgian territory. Also, the FANC performs investigations related to nuclear safety and supervises, controls and inspects nuclear applications. In addition, the FANC is active in the field of radiological protection, training and the dissemination of information and maintains contacts with the Authorities and national organisations concerned and interventions in case of emergency. The Agency provides technical support to the Minister of Internal Affairs. Its statute and working mode ensures a large autonomy and independence from external influence.

With the establishment of the FANC, the legislator has redefined the relationships between the nuclear regulator, the nuclear operators and the specialised control organisations. By statute, the FANC can operate independently and exercise impartially its responsibilities as regulator towards the operators and owner of nuclear facilities. In compliance with the RD-2001 [7], the FANC is the competent authority concerning:

- The licensing of nuclear activities including:
    - The issuing of establishment and operation licenses for nuclear facilities (RD-2001 Art. 5-9);
    - The licensing of professional activities implying the use of radiation sources (RD-2001 Art. 9);
    - The licensing of activities concerning the dismantling of nuclear facilities (RD-2001 Art. 17);
    - The licensing of activities concerning the removal, recycling or re-use of solid radioactive wastes (RD-2001, Art. 18);

- The supervision and the application of the regulation concerning basic norms on the protection against exposure to ionizing radiation, physical and medical control, general measures and procedures concerning protection, radioactive wastes (RD-2001 Art. 20-37).
- The supervision and the application of the regulation including licensing of the import, the export, the transit and the distribution of radioactive substances (RD-2001 Art. 38-44);
- The supervision and the application of the regulation including licensing concerning the use in medicine and veterinary medicine of spent non-sealed radionuclides (RD-2001 Art. 45-49);
- The supervision and the application of the regulation including licensing concerning medical applications of ionizing radiations (RD-2001 Art. 50-55);
- The supervision and the application of the regulation including licensing concerning the transport of radioactive substances (RD-2001 Art. 56-60);
- The supervision and the application of the regulation including licensing concerning nuclear propulsion (RD-2001 Art. 61-63);
- The supervision and the application of the regulation concerning exceptional measures (emergency planning) (RD-2001 Art. 66-69);
- The supervision and the application of the regulation concerning the monitoring of radioactivity on the Belgian territory, the dose by the population including emergency planning (RD-2001 Art. 70-72);
- The licensing of experts, organisations and medical doctors (RD-2001 Art. 73-75).

By the provision of Articles 28 to 30 of the Law of 15 April 1994, the FANC may delegate certain tasks to authorised inspection organisations. The conditions for the recognition of authorised inspection organisations as well as their tasks and responsibilities are laid down in Articles 74 of the RG-2001. These requirements include, among others, the requirement to have the status of a non-profit organisation, the obligation to report on its activities on a quaternary basis to the ‘Surveillance Commission’, chaired by a representative of the FANC, the condition to perform its missions by authorised experts and the requirement to be covered for civil liability [8]. The FANC utilises this provision and has delegated certain tasks among which routine inspections in nuclear power plants to the Association Vinçotte Nucléaire (AVN). The Association Vinçotte Nucleaire (AVN) is the control organisation recognised by the FANC and in charge of performing inspection in nuclear power plants and waste processing facilities.

3.1.1.5 The Belgian radioactive waste management agency NIRAS/ONDRAF

The Belgian Radioactive Waste Management Agency NIRAS/ONDRAF was created by the *law of 8 August 1980* [9] as a:

> *“public organisation in charge of managing the storage of conditioned radioactive waste, disposal of radioactive waste, transport of radioactive waste and enriched or plutonium-containing fissile material, as well as the storage of plutonium. The organisation is further in charge of conditioning radioactive waste originating from installations that do not possess their own equipment to perform one or more of these operations”.*

The tasks and modes of operation of NIRAS/ONDRAF have been laid down in the *Royal Decree of 30 March 1981* [5]. With the creation of NIRAS/ONDRAF, the responsibility for the management of radioactive waste was entrusted to one single institution under public control. The missions of NIRAS/ONDRAF were extended by the *law of 11 January 1991* and its application *Royal Decree of 16 October 1991* [10,11] to include:

> *"long-term research programmes, to define solutions for final repositories, propose specifications for waste exemption or clearance, take charge of excess fissile materials and oversee the decommissioning of the installations"*.

A new mission was assigned to NIRAS/ONDRAF by *article 9 of the general law of 12 December 1997* [12], in particular to:

> *"establish and maintain up to date an inventory of all nuclear facilities and sites containing radioactive substances"*.

By these new legal clauses, the creation of liabilities is avoided by ensuring that each operator of a nuclear site or facility secures, during operation, the funds required to the decommissioning and the rehabilitation of facilities, sites, substances and materials when activities have ceased. The amount of the fees to be paid by the operators to NIRAS/ONDRAF for performing this task has been set by the Royal Decree of 31 May 2000 [13].

In its capacity of implementing organisation, NIRAS/ONDRAF is responsible for - among others:

- The management and the development of the Belgian programme of methodological R&D. This programme investigates the technical and economical feasibility of radioactive waste disposal in a geological repository without prejudging the final disposal site;
- the issuing of acceptance criteria for radioactive waste and the verification of the compliance of conditioned radioactive waste with these criteria;
- The technical and financial implementation of activities related to radioactive waste management in Belgium.

3.1.2 National waste classification scheme

According to the Belgian waste classification systems, distinction is made between the following three general radioactive waste categories [4]:

- **Category A waste** consists of radioactive waste containing low concentrations of radioelements with short half-lives.
- **Category B waste** includes radioactive waste containing radionuclides with medium or long half-lives in relatively high concentrations. The volumic thermal power at the moment of disposal of category B waste is equal to or lower than 20W/m^3.
- **Category C waste** contains very substantial amounts of beta and alpha emitters. Heat generation at the moment of disposal of this waste type exceeds 20 W/m^3.

The Belgian classification system is consistent with the system proposed by the IAEA: category A corresponds to low- and intermediate level short-lived (LILW-SL), category B with low- and intermediate level long-lived (LILW-LL) and category C with high-level waste (HLW).

The radiological characteristics of category A waste allow for waste management options other than geological disposal, for example surface disposal. Radioactive decay must allow this waste to attain a radiological level that is viewed as insignificant over a period of time that is compatible with the institutional control of a surface repository (200 to 300 years).The waste management option for category B and C waste is geological disposal. Both category B and C contain such radio-isotopes in such activity concentrations that their permanent isolation from the biosphere is imperative, and that this therefore constitutes the only ultimate disposal solution.

3.1.2.1 The concentration criterion (criterion X)

Table 4 contains a list of radionuclides that have been identified in the Belgian programme as important in terms of long-term safety applicable to category A waste [14,15]. This list has been established on the basis of the evaluation of the radionuclides that are considered important in relation to category A waste by other industrialised countries with important nuclear programmes. These countries are Canada, Germany, France, Sweden, Switzerland, the United Kingdom and the United States.

In Belgium, category A waste is determined on the basis of a radiological criterion. In particular, category A waste contains only radionuclides with volumetric activity concentration that are sufficiently low to allow for surface disposal. In 1994, a list of twenty radionuclides has been established of which the concentration in the conditioned waste (expressed in Bq/m^3) has to fulfil the so-called concentration criterion. In particular, the maximum allowable initial activity concentration of these radionuclides is required to be lower than or equal to the values listed in Table 4.

Radionuclide	C_i max (Bq/m^3)
^{241}Am	$4.20\ 10^{9}$
^{14}C	$6.60\ 10^{14}$
^{36}Cl	$6.00\ 10^{13}$
^{137}Cs	$3.90\ 10^{11}$
^{3}H	$1.70\ 10^{21}$
^{129}I	$2.30\ 10^{12}$
^{94}Nb	$1.40\ 10^{9}$
^{59}Ni	$1.00\ 10^{15}$
^{63}Ni	$1.60\ 10^{15}$
^{237}Np	$4.20\ 10^{9}$
^{238}Pu	$1.50\ 10^{10}$
^{239}Pu	$2.80\ 10^{9}$
^{240}Pu	$2.90\ 10^{9}$

^{241}Pu	$1.20\ 10^{11}$
^{226}Ra	$8.70\ 10^{8}$
^{90}Sr	$6.30\ 10^{14}$
^{99}Tc	$1.40\ 10^{18}$
^{234}U	$9\ 10^{9}$
^{235}U	$5.40\ 10^{9}$
^{238}U	$1.00\ 10^{10}$

Table 4 - Maximum allowable radionuclide concentrations in the waste packages (dose limitation: 0.3mSv/j after 200 years of institutional control) (reference [14,15])

The concentration criterion has been established for a generic disposal facility and is subject to change in case of future safety evaluations in the framework of the design of a site-specific disposal facility and/or new criteria imposed by the Belgian government. The current criteria are compliant with the general recommendations by the IAEA and the EC which require that individual waste packages containing low- and intermediate level short-lived waste shall contain at maximum 4000 $Bq.g^{-1}$ long-lived alpha activity and that a facility should contain at maximum an average of 400 $Bq.g^{-1}$ long-lived alpha activity.

For each of the twenty radionuclides listed in Table 4, the sum of the ratios of the concentrations of the radionuclides in the waste packages to the maximum allowable activity concentration has to be lower than one. The sum of above mentioned ratios is known as 'criterion X' and is calculated as follows:

$$X=\Sigma(C_i/C_{i,\, max})$$

In case that the value of X is equal to or greater than one, the waste package does not comply with criterion X and is classified as category B or category C waste (depending on the thermal heat output).

3.1.2.2 The activity criterion (criterion Y)

In Belgium, a second operational criterion has been developed in order to take account of the maximum allowable activity in a facility for the disposal of category A waste. This criterion is know as the so-called 'activity criterion' (or criterion Y). Criterion Y is defined as the sum of the ratios between the activity concentrations of the radionuclides listed in Table 4 (C_i) and CB_i where CB_i is defined as the ratio between the total radiological capacity of the site for radionuclide i and the total volume of the disposed waste.

$$Y=\Sigma(C_i/CB_i)$$

The values for the total radiological capacity of a site have been determined for three generic sites taking into account a dose limitation of 0.3 $mSv.year^{-1}$ for the 95th percentile for scenarios for the gradual leaching of radionuclides from the facility to the groundwater through exposure via a water well and a river.

The three general radioactive waste categorises A,B and C are summarised in Table 5.

Waste category	Waste characteristics	Concentration criterion	Criterion X	Criterion Y	Volumic thermal power at the moment of disposal
A	Low- and intermediate level short lived	Table 4	<1	<1 (or>1[2])	≤ 20 W/m^3
B	Low- and intermediate long-lived				≤ 20 W/m^3
C	High-level long-lived				> 20 W/m^3

Table 5 - Waste classification scheme for waste categories A, B and C

3.1.3 National final disposal strategy

3.1.3.1 Geological disposal

In Belgium, the current waste management option for category B and C waste is geological disposal. Research on the geological disposal of high-level and long-lived radioactive waste started in Belgium in the 1970's and is in progress. Until now, research has concentrated mainly on the Boom Clay formation, which is a Tertiary clay formation. Part of the research is performed in the HADES Underground Research Facility (Mol, Belgium), which has been built in the Boom Clay Formation at a depth of approximately 224 metres below surface level.

In the present state of affairs, the Belgian repository development programme is in the so-called third phase of methodological R&D, i.e. aiming to assess whether geological disposal is technically and economically feasible without prejudging the choice of the disposal site or host rock. The main objective of the third phase is to resolve a number of outstanding key issues in order to move progressively from the phase of methodological R&D to a pre-project phase. The pre-project phase will be host rock and site specific. The PRACLAY demonstration project will mark this transition and is intended to demonstrate the technical feasibility of the geological disposal of HLW in a clay formation, taking into account the Belgian reference design. The PRACLAY project will also to corroborate results obtained by the methodological R&D work and thus act as a pivot between both phases. The PRACLAY project is planned for the period 1995-2015 (with the large scale *in situ* demonstration experiment planned for the period from 2008 to 2013).

It is anticipated that, a few years after the start of operation of the PRACLAY demonstration experiment, a sufficiently high level of confidence in the feasibility will be established so as to

[2] In case that X<1 and Y>1, the waste package may be accepted for surface disposal on the condition that the residual radiological capacity of the disposal site remaining after the disposal of the waste package that fulfill both criterion X and Y (i.e. X<1 and Y<1) is sufficiently high

start a first iteration of a 'Safety and Feasibility Report' for the disposal of category B and C waste in clay. This report, which is anticipated by 2010, will provide a basis for successive iterations addressing aspects of feasibility and safety. The report will be elaborated in close consultation with the Belgian nuclear safety authorities.

A second iteration of a 'Safety and Feasibility Report' will be performed by approximately 2017 and lead to the drafting of a report that will review all results obtained with particular emphasis on those aspects that support confidence in the models and predictions. The second Safety and Feasibility Report' can also provide a basis for the decision to move from the methodological R&D phase to the pre-project phase. In the pre-project phase, the disposal system will be qualified for all waste concerned and for a specific host formation and site.

3.1.3.2 Surface disposal

On January, 16th 1998, the Council of Ministers decided to opt for developing a long-term solution regarding the management of low-level and short-lived waste (or for a solution that could become final). At the same time, the Belgian Radioactive Waste Management Agency NIRAS/ONDRAF was asked to pursue two possible solutions for the long-term management of low- and intermediatelevel short-lived waste: surface disposal and deep disposal. ONDRAF/NIRAS was requested to restrict investigation to the four existing nuclear zones in Belgium: Doel, Fleurus, Mol-Dessel and Tihange, and to the local towns or villages that are interested in preliminary field studies. It also had to develop techniques for integrating a project of this nature at a local level. At the end of the project, NIRAS had to provide the government with the necessary elements to enable the latter to make a technical and economic choice between surface disposal and deep disposal, under comparable safety conditions and with regard for the environment.

Following the decisions by the Council of Ministers on 16 January 1998, NIRAS/ONDRAF established local partnerships between NIRAS and the municipalities that have a nuclear zone on their territory : STOLA-Dessel in Dessel (founded on 30 September 1999), MONA in Mol (founded on 9 February 20000) and Fleurus-Farciennes (founded on 27 February 2003). Each of these partnerships was asked to develop a technical predesign for the disposal of category A waste thereby integrating the proposed solution in a broader economic project with involvement of and interaction with the (local) stakeholders.

On 5 November 2004, STOLA-Dessel submitted to Dessel council an integrated project proposal for the disposal of low- and intermediate-level short-lived waste. In January 2005 Dessel council accepted this report for implementation of low- and intermediate-level short lived waste on its territory. After acceptance by the council of NIRAS, this report was delivered on 25 May 2005 to the supervisory Minister Verwilghen. On January 2005, MONA submitted to the Mol council an integrated project proposal for the disposal of low- and intermediate-level short-lived waste. In April 2005 the Mol council accepted this report for implementation of low-level and medium-level short lived waste on its territory. After acceptance by the council of NIRAS, this report was delivered on 13 July 2005 to the supervisory Minister Verwilghen. The final report of the PaLoFF partnership in the Walloon municipalities of Fleurus and Farciennes is finished in December 2005. The decision of the town council is expected early in 2006.

For the next phase, consultation is planned with all involved parties (i.e. waste producers, the federal, regional and local authorities, follow-up committees and NIRAS/ONDRAF) in order to select a proposed project that will be further developed and implemented.

3.1.4 Inventories, conditioning and disposal strategies for existing HTR waste

3.1.4.1 Inventories and conditioning

In the current state of affairs, no spent nuclear fuel or conditioned waste arising from the operation of HTR reactors has been produced as part of the Belgian nuclear programme. Accordingly, back end options for the management of waste arising from the operation of HTR are discussed on a conceptual basis.

3.1.4.2 Direct disposal of spent HTR fuel

According to the Belgian waste classification scheme, spent fuel from HTR is qualified as category C waste. Since HTR spent fuel contains high initial concentrations of long-lived radionuclides and elevated values regarding thermal output, **direct disposal** is the only possible strategy in Belgium with respect to its final disposition. However at present, no specific repository design for the disposal of spent HTR fuel has been developed in Belgium. Accordingly, the compatibility of spent HTR fuel with disposal in a clay formation necessitates further detailed assessment. On the basis of in-depth safety evaluations, the criteria for the acceptance of this waste and functional requirements of a geological repository the disposal of HTR fuel can be specified. Based on this, the repository design and engineered barrier system may be adapted in order to comply with these requirements.

3.1.4.3 Disposal of reprocessing HTR waste

In case of reprocessing, the disposal strategy that can be pursued for the separated constituents (fuel matrix, particles, compacts or pebbles) is imposed by the radiological characteristics and thermal output of the conditioned waste. Depending on the waste category of the conditioned reprocessing HTR waste, surface or a geological repository can be considered as potential routes for the final disposition of this waste form. Conditioned reprocessing HTR waste can be disposed of in a surface repository only on the condition that the waste packages concerned comply with the criteria applicable for category A waste. It is understood that detailed safety evaluations are required on the basis of which the compatibility of these waste packages with disposal in a surface facility can be evaluated. For conditioned reprocessing of HTR waste belonging to waste categories B or C, geological disposal is the only potential disposal strategy.

3.2 France

This section outlines the French institutional and regulatory framework relating to the management of radioactive waste. The role and competence of organisations involved in radioactive waste management in France are briefly reviewed, and the national classification scheme is described.

3.2.1 Waste management regulatory framework and legislation

The national policy on radioactive waste must ensure the protection of individuals, preservation of the environment and limitation of undue burdens imposed on future generations. An extensive regulatory system has been set up for the control of the safety of nuclear activities, including waste management. It consists of laws, decrees and guidance rules.

In France, nuclear operators and waste producers have the responsibility to dispose of their waste in a suitable manner. The competent authorities regulate and control the radioactive waste management activities.

A specific public agency, Andra, has the responsibility for the long-term management of radioactive waste. This agency operates waste repositories, defines the acceptance criteria for waste packages in these repositories and controls the quality of their production. It also keeps a national inventory of waste in France.

The French Nuclear Safety Authority (ASN) is entrusted with the definition and application of the regulations of the main nuclear facilities, known as “basic nuclear installations” (BNIs) such as nuclear reactors, fuel cycle plants, shut-down nuclear facilities, waste treatment plants, radioactive waste interim storage and final repositories. It has also been entrusted, since 2002, with the definition and application of the regulation for remediation of sites and buildings stemming from shut down nuclear facilities, for management of contaminated sites by radioactive material and for radioactive material, management of radioactive waste.
The ASN reports to the ministries for industry and environment, for nuclear safety related issues and to the ministry for health, for radiation protection issues.

The main technical support organization to the ASN is the “Institut de radioprotection et de sûreté nucléaire” (IRSN), created in February 2002. IRSN is an independent public agency.

General laws and regulations for nuclear industry apply to nuclear waste management. Additionally dedicated recommendations for safety were issued: Basic Safety Rules (RFS). Several of them are specifically dedicated to waste. They are not regulatory documents: RFS draw up the safety objectives without imposing the way they can be reached but they describe accepted practices deemed compatible with these objectives.

3.2.1.1 Basic Safety Rules related to radioactive waste management

- RFS I.2: Safety objectives and design basis for surface disposal of short-lived, low and intermediate level radioactive waste.
- RFS III.2.a : General safety measures for production, control, treatment, conditioning and interim storage of reprocessing waste

- RFS III.2.b,c,d: Particular safety measures for production, control, treatment, conditioning and interim storage of waste from reprocessing to be conditioned in glass, bitumen, concrete matrix.
- RFS III.2.e: Conditions prior to acceptance of solid waste in surface disposals.
- RFS III.2.f: Definitions of safety objectives for disposal of radioactive waste in deep geological formations in the post-closure phase.

3.2.2 National waste classification scheme

The various types of radioactive waste produced in France vary considerably by their activity levels, their half-lives, their volumes or even their contents. The treatment and final disposal solution must be adapted to the type of waste involved in order to manage it safely. For the French Nuclear Safety Authority, the management strategy adopted must cover all waste categories.
The following scheme (Table 6) shows the stage reached in the implementation of the different waste management channels. The absence to date of definitive disposal solutions for certain categories of waste is noted.

<table>
<tr><th>Half-life

Activity Bq/g</th><th>Short lived waste (main nuclide half-life< 30 y)</th><th>Long lived waste (main nuclide half-life> 30 y)</th></tr>
<tr><td>V.L.L.W
A< 100</td><td colspan="2">Dedicated surface disposal : CSTFA Moronvilliers (650 000 m³) / recycling channels
(eg: Scrap metal, rubble…)</td></tr>
<tr><td>L.L.W
100 <A< 10⁵</td><td rowspan="2">- Surface disposal at the Aube repository eg: Technological waste (filter….)

- Recycling of certains metals(under investigation)

- (*) tritiated waste</td><td>(**)
(Eg: graphite waste)</td></tr>
<tr><td>I.L.W
10⁵ <A< 10⁸</td><td>Waste management channels (law 1991)
(Eg: Fuel structural waste from reprocessing)</td></tr>
<tr><td>HLW
10⁸ <A< 10¹⁰</td><td colspan="2">Waste management channels (law 1991)
(Eg: Fission products glassified from reprocessing)</td></tr>
</table>

(*) tritiated waste : dedicated disposal facilities under investigation
(**) waste containing radium and graphite : dedicated disposal facilities under investigation

Table 6 – Summary of French Waste Classification and Management Scheme

3.2.3 National final disposal strategy

The management of long lived and high level activity nuclear waste in France is governed by the law passed in December 31st, 1991. The law requires 15 years of research, prescribes that a National Review Board be created, an audit the of different actors, and the publication of an annaul report to the government. Associated to this law, decrees authorize ANDRA to create and operate at Bure (Meuse) an underground laboratory in order to study deep geological formations for disposal of high-level waste and long-lived radioactive waste.

The three major researches directions are:

- Partitioning and transmutation of radioactive elements: separation of different radionuclides, followed by their specific conditioning and/or the transmutation of long half life isotopes to reduce their long term radiotoxicity
- Deep geological storage: burial of duly conditioned waste in a suitable geological formation
- Conditioning and long term surface storage: safe interim storage for long duration

Research is done in partnership between public research organizations and industry in a large number of French and foreign laboratories.

To coordinate the different research actions, the Ministry of Research created a committee in 1993 (COSRAC) that includes representatives from CEA, Andra and CNRS, as well as representatives from industry and other Ministries. This committee coordinates the different organizations, synthesizes the result of their work and determines in association with them the inflections required in their research programs.

After an in depth analysis of the new results with the research partners, COSRAC writes a report every year which describes the recent advances in the field and puts them into perspective for a coherent presentation of the possible solutions to the French government at the expiration of the law in 2006. This document is presented every year to the National Review Commission (CNE).

As for the research relative to the management of high level and long-lived waste the Law of 30 December 1991 prescribes that a National Review Board be created, audit the different actors of this research and publish a report to the government each year

3.2.4 Inventories, conditioning and disposal strategies for existing HTR waste

There are no HTR reactors in France and no existing radioactive waste associated. However, the first generation of Gas Graphite Reactors (UNGG) have produced graphite waste arising from :

- graphite stacks from reactor cores as reflector or moderator materials,
- graphite sheathing surrounding metallic fuel bars.

Graphite stacks coming from shut down reactors are always on the site where they used, waiting for a complete dismantling of the reactor. Graphite amounts to consider are the following :

- At Marcoule, G1, G2 and G3 reactors, 3610 tonnes,
- At Chinon, A1, A2 and A3 reactors, 5780 tonnes,
- At Saint Laurent, A1 and A2 reactors, 5010 tonnes,
- At Bugey reactor, 2040 tonnes.

A first evaluation (calculations considering activation of graphite impurities) about radiological inventory has been carried out with graphite arising from Bugey reactor for a cooling time equal to 5 years. The mains results are :

- ^{3}H ; 6.9 10^{6} Bq/g of graphite,
- ^{14}C ; 3 10^{5} Bq/g of graphite,
- ^{60}Co ; 1.8 10^{6} Bq/g of graphite.

The results have to be compared to the requirements of the ANDRA waste surface disposal center, in particular with the mass activity limits for ^{3}H (2. 10^{5} Bq/g) and ^{14}C (9.2 10^{4} Bq/g). As observed, both ^{3}H and ^{14}C activity levels in graphite from Bugey reactor are too high. In addition, the activity limit for ^{14}C at the Aube center is 8.15 10^{14} Bq. So, considering that the 2000 tonnes of graphite from the Bugey are sent to the surface disposal, the resulting stored activity is close to the limit. As a consequence, contaminated graphite from UNGG reactors can not be stored on a surface disposal site in France.

Other graphite waste (fuel sheathing, experimental fuels) represent about 5000 tonnes.

In France, deep and subsurface disposal type repository are studied. Both could be suitable to the graphite waste management but the subsurface disposal site seems to be more adapted because it could be devoted to non irradiating waste containing long lived radionuclides and the cost will be lower that in a deep disposal one.

3.3 Germany

In this section, the institutional and regulatory framework in Germany concerning the management of radioactive waste is outlined. The scheme of waste classification and the disposal strategy are described, and the inventories, conditioning and disposal strategies for existing HTR waste briefly reviewed.

3.3.1 Waste management regulatory framework and legislation

The German nuclear regulatory framework is a hierarchically structured system, as it is outlined in Figure 2. The pyramid is structured from concrete (bottom) to general requirements (top), with the legal binding on top.

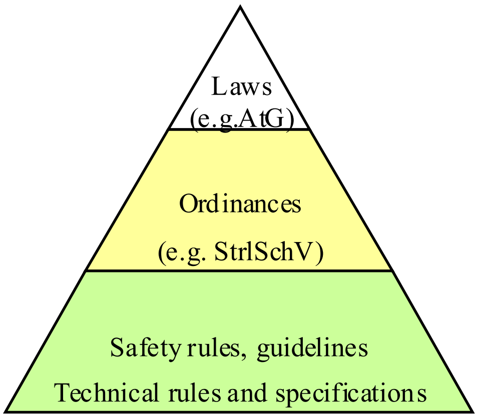


Figure 2 - Hierarchy of nuclear regulatory framework

The handling of nuclear waste is primarily based upon the Atomic Energy Act (Atomgesetz, AtG) [16] and the Radiation Protection Ordinance (Strahlenschutzverordnung, StrlSchV) [17], both having legal binding. In addition to these, several other general laws like the Federal Mining Act [18] and special ordinances [19, 20] have to be taken into account, which influence the treatment and disposal of radioactive waste in Germany.

The Atomic Energy Act attributes special responsibilities regarding waste management to the Federal Government, the State Authorities and the waste producers. For disposal of radioactive waste, the competencies are distributed as follows [21]:

The Federal Ministry for the environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, BMU) is - according to the Atomic Energy Act - the responsible Federal Ministry for nuclear safety and radiation protection. It supervises BfS.

The Federal Ministry for Economics (Bundesministerium für Wirtschaft, BMWi) is responsible for staff provision of BGR as Superior Federal Authority in its portfolio.

The Federal Ministry for Education, Science, Research and Technology (Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie, BMBF) co-ordinates and finances site-independent research and development works.

The Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS) is responsible for the construction and operation of federal installations for long-term storage and final disposal of radioactive waste. It initiates and co-ordinates installation-related research and development works. In performing its tasks, BfS may make use of so-called third parties (section 9a, Para. 3 AtG). BfS executes repayment of project-related costs having arisen for the Federal Government by the waste producers.

The Federal Institute of Geosciences and Resources (Bundesanstalt für Geowissenschaften und Rohstoffe, BGR) has to work on behalf of BfS on geoscientific and geotechnical groups of questions with regard to planning, construction and shutdown of repositories.

The German Company for the Construction and Operation of Repositories for Waste Materials mbH (Deutsche Gesellschaft für Bau und Betrieb von Endlagern für Abfallstoffe mbH, DBE) performs on behalf of BfS tasks on planning, construction and operation of federal installations for long-term storage and final disposal of radioactive waste. It is third party within the meaning of section 9a Para. 3 AtG.

On behalf of BMBF the research centres perform basic research and, on behalf of BfS, installation-related research and development works. Contractors of BfS are, among others, the Company for Plant and Reactor Safety mbH (Gesellschaft für Anlagen- und Reaktorsicherheit mbH, GRS), the Research Centre Jülich GmbH (Forschungszentrum Jülich GmbH, FZJ) and the Research Centre Karlsruhe GmbH (Forschungszentrum Karlsruhe GmbH, FZK).

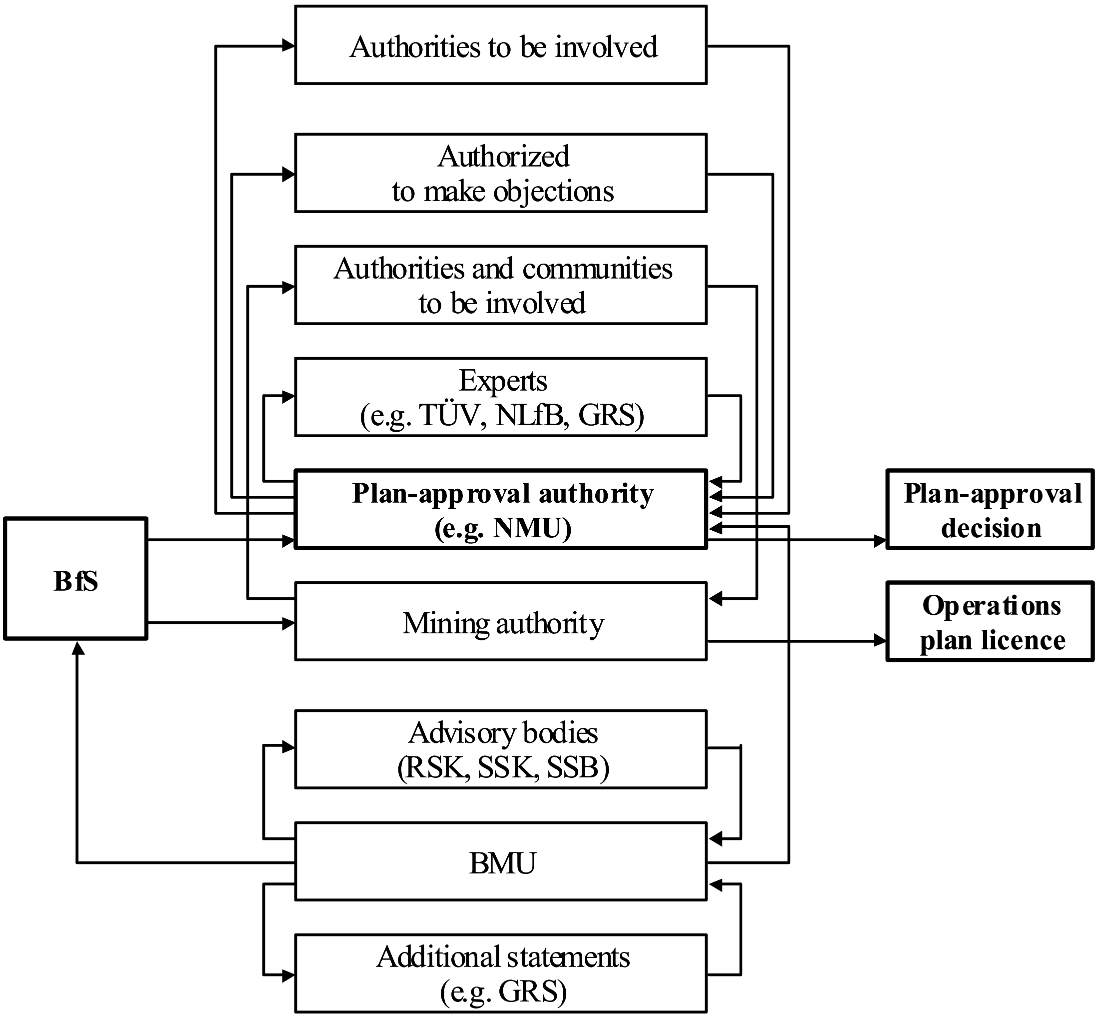
According to the Atomic Energy Act, a procedure is necessary for BfS to obtain approval of the plan for the construction and operation of a nuclear waste repository, as outlined in Fig. 3 The figure shows the linking of the institutions involved in the plan-approval procedure and in the procedure according to mining law. Granting such permission is the responsibility of the licensing authority under the law of the respective States (Länder). However, due to the fact that up to now all potential nuclear waste repositories are located in the State of Lower Saxony, the Minister for the Environment of Lower Saxony (Niedersächsischer Umweltminister, NMU) is in effect the plan-approval authority. As part of this plan-approval procedure, this authority must publish the plan in its official gazette and in the local newspapers, indicate where and when the plan will be made accessible to the public, and invite comments, and discuss them with the public. In addition, a mining authority must license all mining activities.

3.3.2 National waste classification scheme

Nuclear waste varies widely in terms of form, radioactivity and hazardous lifetime. From the handling point of view, the waste producers classify their wastes into categories of low-, medium- and high-level waste. Low-level waste can be handled and stored without shielding, whereas medium-level waste requires shielding measures for safe handling. High-level waste needs additional cooling before being packed and stored/disposed of.

From the disposal point of view, however, such a classification is not sufficient. Acceptance criteria can only be derived from a site-specific safety analysis for each repository site. Because Germany has decided to dispose all kinds of radioactive waste in deep geological repositories, no distinction is made between long- and short-lived waste - as other European countries do - but rather a distinction is made between waste that generates negligible or low heat and heat-generating waste. Negligible heat generation results in a negligible thermal effect (not more than 3 K temperature increase in case of the Konrad mine, see below) upon the surrounding rock.

The BfS has established preliminary waste acceptance requirements for the Konrad repository. These requirements were developed on the basis of the results of a site-specific safety assessment. They include general requirements on waste forms and packagings and limitations for activities of individual radionuclides. Requirements on documentation and delivery of waste packages were additionally included. The following requirements are cited from Ref. [22]:



BMBF	Federal Ministry for Education, Science, Research and Technology
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
GRS	Company for Plant and Reactor Safety mbH
NLfB	Lower Saxony Geological Survey
NMU	Ministry for the Environment of Lower Saxony
BfS	Federal Office for Radiation Protection
RSK	Reactor Safety Commission
SSB	Expert Commission for Aspects of Physical Protection of the Nuclear Fuel Cycle
SSK	Commission on Radiological Protection
TÜV	Technical Control Association

Figure 3 - Course of the plan-approval procedure and the procedure according to the mining law [21]

General basic requirements

Radioactive wastes to be disposed of must not be mixed with substances listed for disposal in accordance with the "Law concerning disposal of wastes (AbfG)" acc. to section 1, par.3 of this law.

Requirements on waste packages

The most important requirements on waste packages include:

- Local dose rate (including the part consisting of neutrons) at the surface of the waste packages is limited to an average of $2 \cdot 10^{-3}$ Sv/h and a local maximum of 10^{-2} Sv/h upon delivery. 1 m away from the surface in case of cylindrical waste packages and 2 m away from box-type containers, the local dose rate must not exceed 10^{-4} Sv/h.
- Non-adhering surface contamination determined over an area of 100 cm^2 must not exceed the limiting value of 0.5 Bq/cm^2 for alpha emitters for which there is a release limit of $5 \cdot 10^6$ Bq , and 50 Bq/cm^2 for beta emitters and electron capture emitters for which there is a release limit of $5 \cdot 10^6$ Bq, and 5 Bq/cm^2 for other radionuclides at any point on the surface of a waste package.

Requirements on waste forms

The various radioactive wastes must be processed in such a way that the resulting waste forms meet the following requirements (basic requirements and special requirements) and so that they can be assigned to one of the following waste form groups:

General basic requirements include:

- Waste forms must be in solid form.
- Waste forms must neither rot nor ferment.
- Waste forms must not contain, with the exception of residue levels achieved by reasonably to be expected effort:
  - Neither liquids nor gases in ampoules, bottles or other containers
  - Neither freely mobile liquids, nor release such liquids under normal storage and handling conditions
  - Neither self-igniting nor explosive materials.
- Waste forms may only contain fissile material in mass concentrations of up to 50 g per 0.1 m^3 of waste form.

The following additional basic requirements apply to waste forms manufactured using an immobilization material (e.g. cement, concrete, bitumen or plastic):

- Reactions between the radioactive waste, the immobilization material and/or the packaging must be reduced to a permissible rate from the safety point of view.
- The immobilization material used must completely be set or solidified.
- Sealing of radioactive wastes or void spaces between inner packagings must be done with suitable free-flowing immobilization materials consolidated, if necessary, by means of technical measures (e.g. vibration).

- Immobilization materials used for the sealing of radioactive wastes or void spaces between inner packagings may also be mixed with contaminated liquids if the quality requirements of the waste form group in question are fulfilled and compatibility with those materials to be cast is guaranteed. Radionuclides contained in the contaminated liquids must be taken into account in activity data.

If radioactive wastes in packages not specified as leak proof can release Rn-220, the waste form must completely be enclosed by at least 40 mm of inactive concrete.

The activity of Kr-85 in a waste package is to be limited to $3 \cdot 10^3$ Bq.

Processing of non-immobilized radioactive wastes in a waste container (e.g. drying or concentration) is permissible if no alterations result that impair the safety barrier function of the container.

The waste forms are to be assigned to one of six waste form groups. These differ as to the safety requirements governing the quality of a waste form. If the quality requirements of a waste form group are fulfilled, the waste form may go up to the allowable limit for the particular waste form group.

Waste form group 01 (e.g. bitumen and plastics):
The basic requirements must be fulfilled for waste forms in this group.

Waste form group 02 (e.g. solid matter):
In waste forms assigned to this waste form group it must be ensured that, in addition to the basic requirements, flammable waste substances with a melting point below 300°C
- are processed so that they will not be discharged from the waste form upon turning liquid under thermal load or
- contribute no more than 1 % of the activity in the waste form.

Waste form group 03 (e.g. metallic solid matter):
In waste forms assigned to this waste form group it must be ensured that, in addition to the basic requirements, the form only consist of metal parts or materials from parts of a reactor core with the exception of graphite.

Waste form group 04 (e.g. compacted waste):
In waste forms assigned to this waste form group it must be ensured that, in addition to the basic requirements, the radioactive waste has been compacted at a pressure of at least 30 MPa so as to have a stable form.

Waste form group 05 (e.g. cemented wastes):
In waste forms assigned to this waste form group it must be ensured that, in addition to the basic requirements, the radioactive waste is fixed in hardened cement paste or concrete so that

- in the case of bound or solidified radioactive waste (e.g. ashes, powders or aqueous concentrates) the activity is homogeneously and completely distributed in the hardened cement paste or concrete
- in the case of sealed radioactive wastes (e.g. scrap) the activity - if technically feasible on the basis of the nature of the wastes - is distributed as evenly as possible throughout the waste form and
- the pressure resistance of the waste form is at least 10 N/mm^2.

Waste form group 06 (e.g. concentrates):
In waste forms assigned to this waste form group it must be ensured that, in addition to the basic requirements, the waste form itself consists of a solid body with a pressure resistance of at least 10 N/mm^2.

<u>Requirements on waste containers</u>
Radioactive waste forms must be packaged for transport, handling and stacking. The waste packages must fulfil type structural requirements as well as the following basic requirements:

In particular, the waste containers must
- have the external dimensions and gross volumes listed (waste containers used for the packaging of radioactive wastes, for example from reprocessing of spent fuel elements from German nuclear power plants, in other European countries may be excepted from the external dimension requirements if the other requirements are fulfilled (including operational conditions))
- be designed such that, when full, they can be stacked over 6 m high without adverse effects on tightness and integrity
  - if they have a specified leak proof rating, their design or correspondingly leak proof inner packaging of the waste form ensures that said rating is maintained
  - and, if made of sheet steel, they must be corrosion protected and have a suitable surface coating (e.g. primer and cover coat)
- be free of obvious mechanical and corrosive damages upon delivery, which adversely affect their tightness and integrity during handling and stacking.

Waste containers can be assigned to two waste container classes that differ from a safety point of view as to packaging quality requirements. If the quality characteristics of one of the waste container classes are fulfilled, the activity limit for the waste form group in question in this waste container class may then be utilized in its entirety.

Waste container class I:
The waste containers are, in addition to the basic requirements, designed so as to maintain their integrity at an impact speed of 4 m/s or less in such a manner that subsequent thermal load (damaging fire, 800°C for 1 hour) causes only limited oxygen leakage to the waste form, such that flammable waste forms with a melting point of over 300°C do not burn off with an open flame, but rather pyrolyse.

Waste container class II:
The packagings must, in addition to the basic requirements, ensure that

- they withstand a drop from a height of 5 m onto an unyielding target so that the total leak rate (in relation to standard conditions as in the leak test with vacuum) does not exceed $1 \cdot 10^{-4}$ Pa·m^3/s or
- in the case of immobilized radioactive wastes in stable form or packaged in inner packagings, the integrity of the inner packaging is maintained after a drop from a height of 5 m onto an unyielding target and
- the walls of the packaging have a thermal resistance (product of layer thickness and reciprocal thermal conductivity) up to an impact speed of 4 m/s of at least 0.1 m^2·K/W or
- in a damaging fire with a temperature of 800°C for one hour it is ensured that the total leak rate (in relation to standard conditions as in the leak test with vacuum) prior to the fire is less than $1 \cdot 10^{-5}$ Pa·m^3/s and the amount of gas released from the packaging during the fire and a cooling-off phase of 24 hours does not exceed one mole.

Activity limitations
Permissible activities for radionuclides and radionuclide groups (no-specified alpha and beta/gamma emitters) result from safety assessments for the operational and post-operational phases of the Konrad repository. The requirements derived there from apply independently of each other. The most stringent requirement in each case regarding permissible activities of radionuclides and radionuclide groups in a waste package must be complied with. Reference [22] contains the listings.

Waste package quality control
The proof that the waste acceptance requirements are fulfilled by waste packages is called waste package quality control according to a recommendation issued by the Reactor Safety Commission. The waste producers/conditioners are responsible for compliance with the waste acceptance requirements. BfS, responsible for the operation of the repository, carries out the following measures within the framework of the waste package quality control:

- Qualification of conditioning methods and definition of inspection measures by means of which operations in the installations are controlled independently.
- Checking of the documentation of waste packages to be disposed of from non-qualified processing and carrying out of destructive and/or non-destructive random sampling of such waste packages.

The test and control measures involved are usually carried out by external experts (i.e. Technical Control Association North (TÜV-Nord) and Quality Control Group (PKS) of the Research Centre Jülich) in charge of BfS. Inspection of qualified conditioning installations is to be carried out by experts by order of the supervising authorities according to Atomic Energy Act in agreement with BfS.

3.3.3 National final disposal strategy

Germany has decided to dispose of all kinds of radioactive waste in deep geological repositories. Since such repositories are not yet available, nuclear wastes have to be intermediately stored on surface in interim storage facilities.

The interim storage of radioactive waste with negligible heat generation from nuclear power plant operation is being performed at nuclear power plant sites, in the Gorleben Interim Storage Facility for Radioactive Waste (drum storage facility), the Mitterteich Collection Site in the State of Bavaria, the Esensham Waste Storage Facility, and the Greifswald Interim Storage Facility North (ZLN) at the site of the former Greifswald Nuclear Power Plant (storage of waste from operation and decommissioning of the Greifswald and Rheinsberg Nuclear Power Plants with interim storage of the dismantled large components).

Radioactive waste from nuclear industry and research institutions is mainly stored intermediately at the waste producers sites (e.g. research centres at Jülich, FZJ and Karlsruhe, FZK). Radioactive wastes from medical applications and small-scale waste producers are stored intermediately in Federal State Collecting Depots.

For spent nuclear fuel, both reprocessing/reuse of reprocessed fuel and direct disposal of spent fuel are essential parts of the German waste management concept. Reprocessing contracts were made with COGEMA, France and BNFL, Great Britain as from the 70ies.
In its decision of 6 June 1989, the Federal Government stated that reprocessing in Member States of the EC is accepted as a part of the integrated nuclear waste management concept and, therefore, of the proof for precautionary measures for disposal of spent fuel from German nuclear power plants. In consequence, after having cancelled national reprocessing projects, the Electricity Utilities (Energieversorgungsunternehmen, EVU) have negotiated standardized and individual contracts with COGEMA and BNFL covering fuel transports until mid 2005.

On 6 June 1989, the Federal Government emphasized that, in addition to reprocessing, methods for the direct disposal without reprocessing should be further developed. With the amendment of paragraph 9a AtG in 1994, the direct disposal of spent fuel became of equal rank with reprocessing, i.e. the priority of economic use (recycling) was given up.

In order to prove their technical feasibility and licensing capability to meet the provisions of the Atomic Energy Act relating to conditioning of spent fuel, the utilities planned and constructed the Pilot Conditioning Plant (PKA) for spent nuclear fuel and radioactive waste at the Gorleben site, Lower Saxony. The facility is designed for a capacity of 35 tons of heavy metal (HM) per year. It is conceived as a multipurpose plant, where besides fuel elements, all types of radioactive waste from nuclear power plants can be conditioned in a suitable way for disposal. The construction of the facility is completed, and the licences are granted. However, according to an agreement between the German federal government and the electricity utilities from 14 June 2000 [23] the plant may, for the present, only be used for repairing defect high-active waste and spent fuel containers.

Prior to conditioning and direct disposal, spent fuel has to be stored in interim storage facilities. In addition to the storage capacity in the fuel cooling installations of the nuclear power plants, several additional off-site interim storage facilities (dry storage in Castor type storage and transport containers) are available in Germany: The Ahaus Interim Storage Facility is licensed to store up to 3,960 tons HM from spent fuel (including THTR fuel, see below). The Jülich AVR Container Storage Facility has a capacity of up to 300,000 spent fuel elements from the AVR reactor (see below). The Gorleben Interim Storage Facility has 420 container storage spaces to store spent fuel (up to 3,800 tons HM) as well as solidified high-active waste solutions and other radioactive substances. The Greifswald Interim Storage Facility North is licensed to store spent fuel assemblies (up to 650 tons HM) from the Rheinsberg and Greifswald reactors.

Two repository projects were launched by the Federal Government for the disposal of radioactive waste: The Gorleben salt dome in the State of Lower Saxony has been explored since 1979 with regard to its suitability for the disposal of all types of solid and solidified radioactive waste. The surface site explorations are finished. Two access shafts have been completed, and the intersection between them carried out on the 840-m level in October 1996. A comprehensive geoscientific and geotechnical investigation programme has been carried out. All the results obtained so far confirm that the suitability of the Gorleben site as a repository for all kinds of radioactive waste may be expected.
However, the agreement initialed on June 14, 2000 by the German federal government and the electricity utilities [23] contains a moratorium in exploration for three up to a maximum of ten years in which five conceptual and safety-related questions raised by the Federal government about the suitability of the Gorleben salt dome as a repository for radioactive waste were to be clarified. In September 2005 the BfS published on the Internet the final reports [24] about the studies that had been extended to twelve questions by the German Federal Ministry for the Environment. The outcome is that, in principle, salt is suitable to host a repository. No doubt about the suitability of the Gorleben salt dome can be derived from the reports. As of early 2006, consequences regarding the continuation/termination of the moratorium are still pending.

The planned KONRAD repository, a former iron ore mine near Salzgitter in the State of Lower Saxony, is provided for the disposal of radioactive waste with negligible heat generation, i.e. about 90 Vol% of German radioactive waste in total. From 1977 until 1982, the geological suitability of the mine was certified in an investigation of the Company for Radiation research (Gesellschaft für Strahlenforschung, GSF). This is due to its exceptional dryness. The geological barrier formed by the predominantly clay-rich strata overlying this site is also relatively impermeable to groundwater, thus ensuring the long-term isolation of the waste from the biosphere.
The plan-approval procedure was initiated in 1992, and successfully completed in June 2002. The Higher Administrative Court Lüneburg rejected several actions against this decision in March 2006. A decision of BfS to start retrofitting the abandoned mine into a nuclear waste repository, which will take another five years, is still pending.

3.3.4 Inventories, conditioning and disposal strategies for existing HTR waste

Two HTRs were operated in Germany.

The 15 MWe experimental nuclear power plant with helium cooled pebble-bed high temperature reactor of the Arbeitsgemeinschaft Versuchsreaktor Jülich (AVR) GmbH was shut down in 1988 after 21 years of operation. All fuel elements were removed from the reactor, and some of the equipment outside the reactor vessel was dismantled and disassembled in order to reach safe enclosure. In May 2003 the AVR GmbH became a subsidiary company from the Energiewerke Nord (EWN, Energy Company North), the Federal Ministry of Finance being the only holder. In February 2005, AVR GmbH filed the application for complete dismantling of the plant. The concept includes

- backfilling of the complete reactor vessel including all ceramic internals with a porous light concrete in order to increase the safety during handling and storage,
- unhinging of the reactor vessel from the reactor building,
- transportation of the reactor vessel to an FZJ intermediate storage facility located nearby,
- dismantling and disassembling of all external systems, and
- site restoration.

As of early 2006, preparatory work is ongoing. The project is planned to be finished by the year 2013.

The Thorium Hochtemperaturreaktor (THTR-300, a helium-cooled high-temperature pebble-bed reactor), a full-scale prototype plant at Hamm-Uentrop with 300 MWe capacity, was shut down in 1989 for decommissioning after approximately three years of operation. All fuel elements had been removed from the core by the end of 1994, and specified components were dismantled. The status of safe enclosure was reached in February 1997, which is planned to be continued for up to thirty years.

Whereas most of the HTR operating and decommissioning wastes can be treated and disposed of similar to those arising from LWRs, spent fuel elements and irradiated graphitic core internals need special attention.

Approximately 291,000 fuel elements were irradiated during the operating time of the AVR reactor. They were transported to the Jülich AVR Container Storage Facility for dry interim storage in 157 CASTOR THTR/AVR storage and transport containers.
In the THTR-300, approximately 619,000 fuel elements plus 343,500 absorber and graphite elements were irradiated. They are being stored in 305 CASTOR THTR/AVR storage and transport containers at the Ahaus Interim Storage Facility. Direct geological disposal is foreseen for these irradiated fuel elements using techniques similar to those developed for the disposal of irradiated LWR fuel, i.e. packaging in corrosion resistant shielding containers for the emplacement in drifts or boreholes. However, R&D is ongoing at the Research Centre Jülich to optimize the concept, utilizing the special features of the ceramic HTR fuel element regarding long-term stability in a geological repository.

Approximately 790 tons of carbonaceous materials - graphite from reflector and carbon from insulation/shielding structures - may be expected during dismantling of the core structures of AVR and THTR-300. These materials may represent a special problem in a geological repository due to their contamination and the fact that they are flammable. Volatile radionuclides like C-14 are of major concern. R&D work on the improvement of disposal relevant properties is ongoing at the Research Centre Jülich.

3.4 UK

This section outlines the British institutional and regulatory framework relating to the management of radioactive waste. The role and competence of organisations involved in radioactive waste management in the UK are briefly reviewed, and the national classification scheme is described.

3.4.1 Waste management regulatory framework and legislation

The management of radioactive waste in the UK is currently governed by several Acts of Parliament, and enforced by various governmental organisations. The main area of regulation covering radioactive waste is covered by the Radioactive Substances Act (1993) [25], which was later ammended by the Environment Act (1995). This Act controls the keeping, use, accumulations and disposal of radioactive materials and wastes, and is enforced by the Environment Agency. The safety of workers engaged in the handling of radioactive materials is covered by the Ionising Radiaction Regulations (1985), which is enforced by the Health and Safety Executive (HSE) and the Nuclear Installations Inspectorate (NII). In addition, separate legislation covers the movement of radioactive materials by road, and is enforced by the Department for Transport Radioactive Materials Transport Division (RMTD).

The formulation and implementation of policy for radioactive waste disposal has evolved in the UK over several decades. In 1982 the UK nuclear industry, with the support of the government established the Nuclear Industry Radioactive Waste Executive (Nirex) to implement a strategy for the safe disposal of Low and Intermediate level radioactive wastes. The disposal of High level waste was outside the original remit of Nirex.

Prior to April 2005, Nirex was jointly owned by the major producers of radioactive waste in the UK: British Nuclear Fuels plc (BNFL); Magnox Electric plc (a subsidiary of BNFL); the UK Atomic Energy Authority (UKAEA); British Energy Generation Ltd; and British Energy Generation (UK) Ltd. From April 2005 the Government acquired Nirex and it is now jointly owned by the Department for Environment, Food and Rural Affairs (DEFRA) and the Department of Trade and Industry (DTI). This move to make Nirex independent of the nuclear industry was aimed at improving transparency and accountability in the long-term management of radioactive waste in the UK.

The initial research of Nirex was based around shallow disposal methods. In 1987, after widespread opposition, the government and Nirex abandoned this approach. Nirex started investigating a deep repository for all types of low and intermediate level waste and 500 possible sites were identified and assessed. In 1989 Nirex, the Government and RWMAC agreed to focus on sites at Sellafield and Dounreay. Much of the research activity of Nirex has been based around the Phased Disposal Concept for deep geological disposal of intermediate level waste, which is detailed in Section 3.4.3. Nirex, in conjunction with DEFRA, is also responsible for publishing a detailed UK Radioactive Waste Inventory at 3-yearly intervals [26].

In September 2001, a consultation process called 'Managing Radioactive Waste Safely' (MRWS) was launched by the UK Government. This sets out proposals for developing a policy for managing solid radioactive waste in the UK and included a programme of action for reaching decisions which is divided into stages. In July 2002, the DTI produced a White Paper, 'Managing the Nuclear Legacy: A Strategy for Action' [27] . This announced the intent to establish a new body, The Nuclear Decommisioning Authority (NDA), with responsibility for dealing with the UK's civil nuclear legacy. This was followed in February 2003, by the Energy White Paper, 'Our energy future - creating a low carbon economy' [28]. The NDA formally started operation in April 2005 with a strategic responsibility for the UK's nuclear legacy, and a remit to ensure that 20 civil public sector nuclear sites are decommissioned and cleaned up safely, securely & cost effectively

In response to the initial white paper, the government also appointed a Committee on Radioactive Waste Management (CoRWM), with a remit to oversee a review of options for managing solid radioactive waste in the UK and to recommend the option, or combination of options, that could provide a long term solution. The initial activities of CoRWM were to establish a radioactive waste inventory, a long list of options, and to develop an assessment methodology and decision-making process. A final report to government is scheduled for July 2006.

3.4.2 National waste classification scheme

Radioactive waste in the UK is placed into one of four categories according to its heat generating capacity and activity content [29,30,31]. This categorisation is performed for management purposes rather than for a direct regulatory need and does not directly relate to the disposal route. The classification system is therefore only intended to be indicative of the safety features and targets that each waste type would have to meet.

3.4.2.1 Very Low Level Waste (VLLW)

Very Low Level Waste (VLLW) covers wastes with very low concentrations of radioactivity which can be disposed of with ordinary refuse. To be categorised as VLLW, each 0.1 m^3 of material must contain less than 400 kBq of beta/gamma activity and single items must contain less than 40 kBq. VLLW arises from a variety of sources, including hospitals and non-nuclear industry. VLLW can be disposed with domestic refuse directly at landfill sites or indirectly after incineration.

3.4.2.2 Low Level Waste (LLW)

Low Level Waste (LLW) is defined as that which contains radioactive materials other than those suitable for disposal with ordinary refuse, but not exceeding 4 GBq/te of alpha or 12 GBq/te of beta/gamma activity. Since the 1950s around 1,000,000m^3 of LLW has been safely disposed of in the UK. The main authorised UK disposal sites for LLW is Drigg in Cumbria, although smaller sites including Dounreay in Caithness are also licensed for LLW disposal. LLW for disposal at Drigg is subjected to high force supercompaction of 2000 tonne/m^2 and is placed in metal containers of 15m^3 capacity which are grouted with cement and placed inside a concrete lined vault. The disposal site limit for Drigg is 1,750,000m^3.

In addition to the LLW limits for alpha and beta/gamma activity described above, there are also a further set of Drigg Conditions for Acceptance (CfA), which include radiological criteria for individual nuclides, as shown in Table 7.

Site limits
Uranium activity < 9TBq
Ra226 + Th232 activity < 0.9TBq
Other alpha activity < 9TBq *
C14 activity < 1.5TBq
I129 activity < 1.5TBq
H3 activity < 300TBq
Co60 activity < 58TBq
Other beta/gamma activity < 450TBq *

Criticality Limits
U235 enrichment < 0.71%
U235 content per consignment < 60g
Pu238 + Pu239 + Pu240 + Pu242 < 0.1GBq/te
Pu241 < 12GBq/te
Np237 < 4GBq/te
Am241, Am242 or Am243 < 0.1GBq/te
Th228, U234, U236, Pa231, Pa232, Cm243, Cm244, Cm245 or Cm246 < 1000GBq/te

* (λ > 3months)

Table 7 – Summary of Drigg Conditions for Acceptance

Of particular importance to the issue of activitated graphite waste from high temperature reactors is an additional operating limit placed upon the disposal of ^{14}C. The Drigg CfA place an upper limit of 50GBq on the activity of ^{14}C which can be disposed of per year. There are also Drigg CfA limits placed upon the physical and chemical compositions of the waste, which are not considered here, but are published in [32]. Previous studies [33] have shown that the disposal of treated HTR graphite at the Drigg facility would quickly exceed the site condtions for acceptance.

3.4.2.3 Intermediate Level Waste (ILW)

Intermediate Level Waste (ILW) is defined as that which has radioactivity levels exceeding the upper boundaries for LLW, namely 4 GBq/te of alpha or 12 GBq/te of beta/gamma activity, but which do not need heating to be taken into account in the design of storage or disposal facilities.

ILW currently arises in the UK mainly from the reprocessing of spent fuel, and from general operations and maintenance of radioactive plant. The major components of ILW are steels, graphite, concrete, cement and rubble, and sludges and flocs. The wide range of steel items includes plant items and equipment, fuel cladding and reactor components. Most graphite is in the form of moderator blocks from final stage reactor dismantling at Magnox and AGR power stations.

Most ILW in the UK is currently conditioned by packing the material in 500 litre stainless steel drums. In order to avoid the additional radiological dose to workers and the very high costs that would be associated with re-packaging, conditioning is carried out in such a way as to anticipate the requirements for the future long-term management of the wastes. ILW in raw or conditioned form, is mainly stored in shielded buildings, vaults or silos, mostly at the site where it arises. The majority originates at the Sellafield plant in Cumbria.

After 2020, most UK ILW will arise from decommissioning and in total, about 50% of all expected ILW arising in the UK will be from the decommissioning of existing facilities. Conditioning proposals are assessed by Nirex against principles governing the safety of storage, transport, handling and possible disposal of the wastes.

There is currently no final ILW mangement strategy in place in the UK. Most ILW is stored at the producing sites, although some minor waste producers make use of the UKAEA's ILW store at Harwell and BNFL's facilities at Sellafield. The development of an ILW management policy capable of commanding widespread public support is currently the subject of the CoRWM programme, which is reviewed in Section 3.4.3.

3.4.2.4 High Level Waste (HLW)

High Level Waste (HLW) is defined as that in which the temperature may rise significantly as a result of radioactivity, and in which heat generation must be taken into account in design of storage or disposal facilities.

HLW is initially produced in the UK as a concentrated nitric acid solution containing fission products and some actinides from the primary stage of reprocessing spent nuclear fuel. It is conditioned at the Sellafield Waste Vitrification Plant (WVP) via a vitrification process in which it is immobilised in solid form in borosilicate glass. It is heated to dryness leaving a fine powder, which is mixed with crushed glass in a furnace to produce a molten product incorporating the waste. This is then poured into stainless steel canisters, which hold approximately 150 litres, and a stainless steel lid is welded on. Fresh waste from reprocessing is blended with existing stored liquid waste and vitrified to an agreed programme imposed by the Health and Safety Executive. To date about 460 cubic metres of vitrified HLW have been produced and placed in an air-cooled store.

The UK has been reprocessing spent fuel since the early 1950s and it is currently estimated that by 2015 reprocessing operations will be completed. As with ILW, no disposal route is currently available for HLW in the UK. Current Government policy is that the waste be stored for at least 50 years to allow for the short-lived radionuclides to decay and the heat generation to decline, so as to make long-term management less complex.

It should be noted that there is no distinction or definition in the UK classification schemes between short-lived and long-lived wastes.

3.4.2.5 Materials not classified as waste

In the UK, there are several important streams of radioactive material which are not classified as waste and these are briefly described.

The depleted uranium tails which arise from the uranium enrichment process performed at Capenhurst are not categorised as waste because of their low radiological activity, their potential future use within the manufacture of MOX fuel, and their industrial usage outside of the nuclear industry.

The reprocessing at Sellafield of spent fuel from UK Magnox and AGR stations results in the separation of uranium and plutonium from high level waste. The reprocessed uranium arising from this route has historically been recycled within UK reactors, but is now stored on behalf of the generating utility, British Energy, as a hedge against future uranium ore price rises. The plutonium arising from this route is converted into insoluble plutonium dioxide for indefinite storage. Neither of these materials are therefore classified as waste within the UK.

Stocks of spent fuel in the UK are also currently exempt from classification as waste. Current policy is that the decision to reprocess or hold spent fuel in long-term storage pending direct disposal is a matter for the commercial judgement of its owners, and therefore it is not classified as waste because of the potential value to the owners of the plutonium and uranium content.

3.4.3 National final disposal strategy

The UK has significant holdings of long-lived radioactive waste which have been generated since the 1940's. The waste is currently being stored at 34 locations around the UK awaiting a long-term waste management facility. There has been several unsuccessful attempts to establish such a facility for these wastes. The most recent attempt to implement a deep geological repository to manage intermediate- and low-level wastes ended with a refusal in 1997 from the Secretary of State for the Environment to allow the construction of an underground Rock Characterisation Facility (RCF) close to the Sellafield works in Cumbria.

Following the establishment of CoRWM (Section 3.4.1), the Committee has examined a range of options [34] for managing the UK inventory of radioactive waste, and has screened out a number of options. These include proposals such as disposal at sea, within ice-sheets, within space, and by direct injection into rock layers. Other options including partitioning and transmutation, and incineration were considered as processing options rather than disposal solutions. Four options have been short listed and are described below. These options are, at the time of this review, undergoing assessment, and final recommendations will be made to government in July 2006.

3.4.3.1 Long-term interim storage

Long-term interim storage involves packaging radioactive wastes and storing them in purpose built facilities. Stores can be either above ground or below ground and in the form of a single central facility or a range of local facilities. If above ground, they can be designed to withstand foreseeable attack. With periodic refurbishment, long-term interim stores might last for 300 years or more, depending on the design. In the UK, wastes are currently being stored on an interim basis at the nuclear sites where they are produced, though most spent nuclear fuel is being transported for storage at Sellafield.

CoRWM proposes to consider several variants of long-term interim storage, based on storage of the waste either above ground or underground, and in a centralised location, or at the current location of the waste.

3.4.3.2 Near-surface disposal of short-lived wastes

In this option radioactive waste is buried below ground in a facility with engineered barriers. This may be either just below the surface with a protective covering or several tens of metres deeper in underground caverns or vaults accessed by a tunnel. The important difference from deep geological disposal is that this option does not use the geology to provide a barrier for the waste and is therefore possible in areas without the geological features required for deep geological disposal. It differs from storing wastes underground in that it would involve permanent disposal with no intention to retrieve the wastes in the future. However, the facility could be designed so that if radioactivity were to leak, it could be detected by environmental monitoring and the waste could be removed.

Near-surface disposal is suited to short-lived wastes which lose their radioactivity over a few hundred years. (CoRWM has proposed to eliminate this option for long-lived wastes). Wastes can be disposed of either at a number of sites where they were produced or at a centralised site. The Drigg LLW facility is a current example of this type.

3.4.3.3 Deep geological disposal

This option involves placing packaged radioactive wastes deep underground in places where the geology can provide a secure barrier. The usual model proposed is to excavate a repository several hundred metres underground in natural rock formations. Another approach is to place the packaged wastes in deep boreholes or disused mines which are then sealed off by engineered or natural barriers. The intention is to contain the wastes over the very long timescales during which some wastes remain radioactive (in some cases hundreds of thousands of years) so that the amount of radioactivity which does eventually reach the surface is very small. The intention is to leave the wastes in the repository permanently, with no further intervention. Research into this option is more advanced than for most others, and it has been seriously considered and/or adopted by most countries with a nuclear power programme, and was investigated by Nirex up to1997.

3.4.3.4 *Phased deep geological disposal*

This option involves placing radioactive waste into an engineered repository deep underground in places where the geology can provide a secure barrier. It differs from the previous option in that the repository is designed to function as a store with access and monitoring for an interim period until it is finally closed and backfilled at some future date. At that point the option becomes disposal. Future generations may decide when to close it. It therefore uses similar technology and has the same geological requirements as deep disposal, but with additional features for interim access, monitoring and retrievability. Phased deep geological disposal has been proposed in response to concerns about the difficulty of retrieving waste in the deep geological disposal option. Nirex has developed a concept for this option for ILW in the UK.

3.4.4 Inventories, conditioning and disposal strategies for existing HTR waste

The UK has experience of the defuelling and decommissioning of existing HTR waste due to operation of the Dragon Reactor Experiment (DRE). Dragon was the pioneering experimental reactor of the OECD High Temperature Reactor Project and was situated at Winfrith in the UK. The reactor was designed and built as a fuel and materials test facility and was the world's first high temperature reactor. Criticality was achieved in August of 1964 and full design power of 20 MW was reached in April 1966. Dragon finally shut down in September 1975. The core had a maximum thermal power of 21.5 MW (reached in May 1971) with corresponding core inlet and outlet temperatures of 350ºC and 750ºC respectively.

The core of Dragon was prismatic, hexagonal in cross-section, and was contained within a steel reactor pressure vessel (RPV). Each hexagonal fuel element was made up of a hexagonal graphite top block and a circular nimonic steel bottom ring. Held between the top block and bottom ring was a ring of six driver fuel rods, made up from annular graphite fuel compacts contained within graphite sleeves, and a central rod that contained an experimental section. The six driver rods in each fuel element generally contained highly enriched UO_2, in the form of coated particles bonded into graphite compacts. A coated particle consisted of 0.8 mm UO_2 kernels encased within a triple (TRISO) coating, consisting of a silicon carbide layer sandwiched between two layers of pyrolytic carbon. A wide variety of experimental fuels were tested containing oxide or carbide mixed compounds, involving low enrichment uranium, thorium and plutonium. Reactor control was implemented via control rods inserted into the radial reflector blocks.

Following defuelling of Dragon, 75,000 fuel compacts were stored untreated and were subsequently repackaged in stainless steel cans in 1998. These waste packages contain fuel consisting of uranium and uranium/thorium oxide and carbide kernels, graphite and some ZrC, covered with carbon and SiC layers to give 0.1-0.25 mm particles. The fuel particles are mixed with graphite and compressed into compacts and some of the fuel has disintegrated. Chemically, the composition of the packages can be summarised as follows :

- ~95% graphite/pyrocarbon
- ~5% heavy metal oxides and carbides (U/Th/Zr)
- 14C - graphite and pyrolytic carbon

- Th - Thorium oxide & thorium carbide (ThC & ThC_2)
- U - Uranium oxide and uranium carbide (UC & UC_2)
- Pu - Plutonium oxide and plutonium carbide (PuC)

There is no detailed publically available experimental characterisation or inventory data for the Dragon waste packages, and published inventories are based on calculations using inventory codes. The Dragon waste packages are the property of the NDA, and are classified in the UK as ILW as their heat generation rates are low enough not to require engineered cooling [26]. The situation with regard to the Dragon spent fuel is untypical because of the low heat generation rates, and in general, fuel waste streams arising from the treatment of spent HTR fuel would be classified as HLW.

3.5 USA

This section outlines the US institutional and regulatory framework relating to the management of radioactive waste. The role and competence of organisations involved in radioactive waste management in the USA are briefly reviewed, and the national classification scheme is described.

3.5.1 Waste management regulatory framework and legislation

US Waste Classification is a complex procedure detailed in US classification rules 10 CFR 61.55 and 61.56 that considers:

- Longevity and potential hazard of the constituent radionuclides
- Efficacy of institutional controls for short-lived nuclides
- Proper waste package characteristics
- Suitability of sub-surface burial

Table 8 US Waste Categories - Classification Tables

10 CFR 61.55 Table 1 (Applied First)

Radionuclide	Class A ≤	< Class C ≤	
C-14	0.8	8	Ci/m^3
C-14 in activated metal	8	80	Ci/ m^3
Ni-59 in activated metal	22	220	Ci/ m^3
Nb-94 in activated metal	0.02	0.2	Ci/ m^3
Tc-99	0.3	3	Ci/ m^3

I-129	0.008	0.08	Ci/ m^3
Alpha emitting transuranic nuclides with half-life greater than 5 years	10	100	nanoCi/g
Pu-241	350	3500	nanoCi/g
Cm-242	2000	20000	nanoCi/gr

10 CFR 61.55 Table 2 (Applied Second)

Radionuclide	Class A ≤	< Class B ≤	< Class C ≤	
	C1	**C2**	**C3**	
Total of all nuclides with less than 5 year half-life	700	B	B	Ci/ m^3
H-3	40	B	B	Ci/ m^3
Co-60	700	B	B	Ci/ m^3
Ni-63	3.5	70	700	Ci/ m^3
Ni-63 in activated metal	35	700	7000	Ci/ m^3
Sr-90	0.04	150	7000	Ci/ m^3
Cs-137	1	44	4600	Ci/ m^3

B - No limits for these nuclides, Class B unless Class C independent of these nuclides

3.5.2 National waste classification scheme

In the U.S, waste classification methods are in accordance with 10 CFR 61.55 and disposal facility regulations significantly affect disposal options.

Spent fuel that is not suitable for reprocessing is classified in the U.S. as High Level Waste (HLW). The residue from reprocessing of spent fuel is also classified as HLW or HAVL. HLW must ultimately be disposed of in an appropriate facility (e.g., Mined Geologic Repository or MGR).

Nevertheless, the absence of a reprocessing option leading to ultimately reduce the volume of HLW/HAVL to be stored combined with the lack of a disposal site for Spent Nuclear Fuel

(SNF) and HLW hamper the US commercial nuclear power program. Very few U.S. nuclear sites are not without an Independent Spent Fuel Storage Facility (ISFSI). These facilities temporarily store spent fuel and HLW in dry cask storage until the day comes a repository (Yucca Mountain) become available.

In that case, the U.S. Nuclear Waste Policy Act limits the amount of waste to 70,000 metric tons heavy metal (MTHM) of which 63,000 MTHM is allocated to commercial spent nuclear fuel (i.e., LWR fuel). The remaining 7,000 MTHM is allotted to the US DOE for HLW and non-standard fuels, such as Ft. St. Vrain spent fuel.

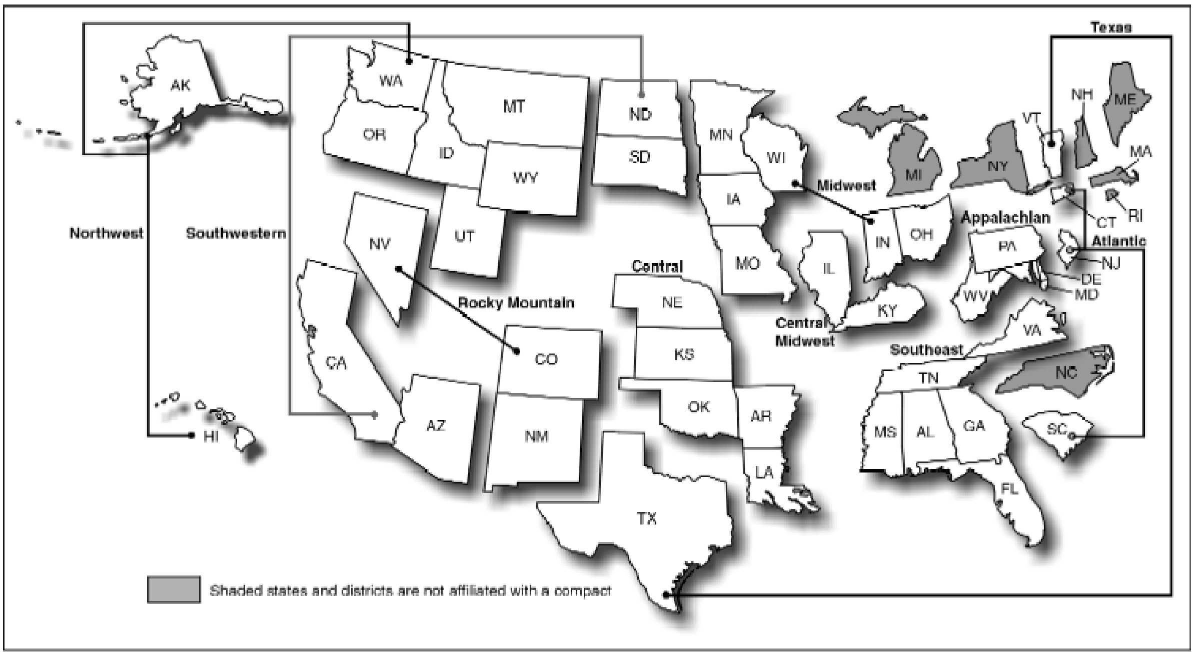
3.5.3 National final disposal strategy

3.5.3.1 Low level waste disposal options: the compact system

Under the 1980 Low-level Radioactive Waste Policy Act and its 1985 amendments, selecting disposal sites for commercial low-level radioactive waste is a state responsibility. There is a “de facto” national disposal system because there are currently a very limited number of LLW disposal sites in operation. This system is called the “compact” system, under which different groupings of states in the USA sought a common LLW repository (Figure 4).

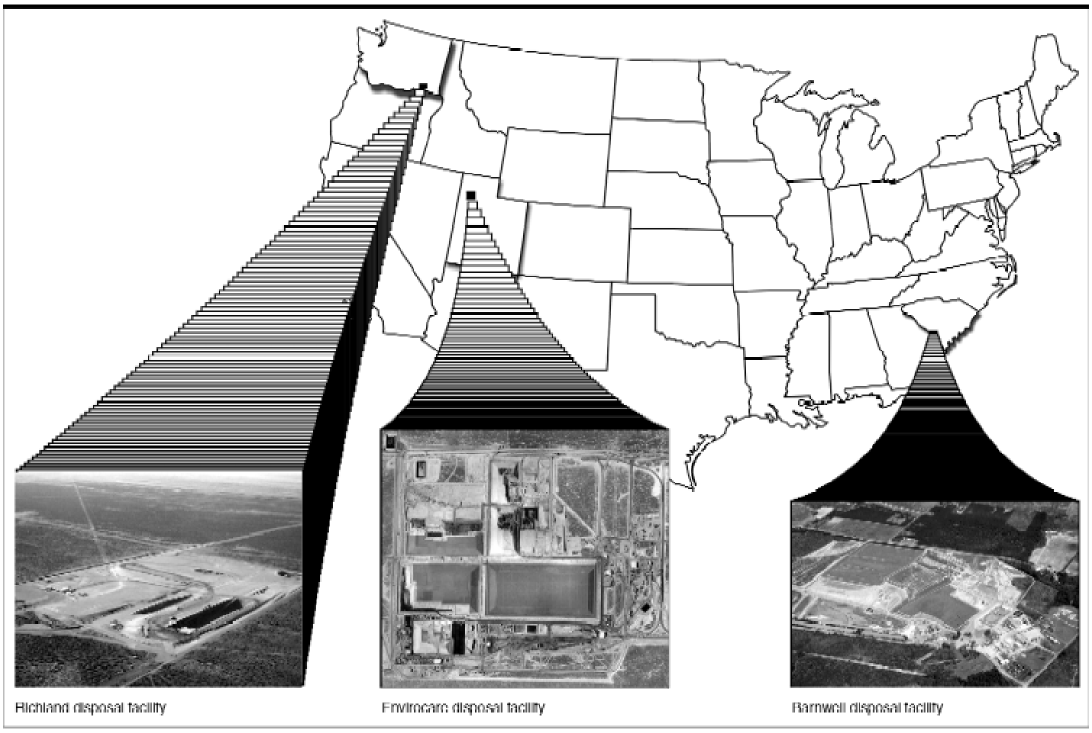
One of the incentives for states to join compacts was that a state that has joined a compact could exclude out-of-compact waste from its regional disposal site, but a state that decides to "go it alone" can't. Most have joined congressionally approved interstate compacts, while others are planning to develop single-state disposal sites.

LLW can be disposed of in a surface repository providing that the waste is classified as U.S. Class C or less. There are currently 3 operating commercial disposal sites for LLW in the United States; Non-DOE Greater than Class C LLW is disposed of in 2 commercial sites, at Barnwell in South Carolina and at Richland in Washington State. Class A, B and C LLW is disposed of at Clive, in Utah (Figure 5). LLW can also be sent to intermediate processors, however, residual waste is then sent to one of LLW facilities.



Sources: NRC and Low-level Waste Forum.

Figure 4 - Access to U.S. LLW Facilities: The Compact System



Sources: US Ecology, Inc., Envirocare of Utah, Inc., Duratek, Inc., and GAO.

Figure 5 - U.S. Operating LLW Sites: Richland (A, B, C), Barnwell (A,B,C) and Envirocare (A)

Capacity of US sites is limited only by VOLUME and not by total accumulated RN inventory.

In 2005 US site capacity available was:

- Barnwell – about 90% full
  - 850,000 M3 total capacity
  - 76,500 M3 capacity remaining
- Richland – about 50% full
  - 963,000 M3 total capacity
  - 595,000 M3 capacity remaining
- Envirocare
  - 540 Acre (212 hectare) site
  - Contains 1.7M M3 Class A Waste
  - 20 years capacity remaining
  - Accepts 99% of US Class A waste

3.5.3.2 Barnwell, S.C.

The Barnwell disposal facility was opened in 1969, but the actual license to use about 17 acres of land for shallow burial of LLRW in Barnwell County, South Carolina, was issued in 1971. This commercial site is located near the much larger Savannah River Site owned by DOE. In 1976, the site was expanded to its present size of 235 acres with an original capacity to hold 30.6 million cubic feet of all classes of radioactive waste and some other types of waste.

South Carolina is the current host state for the Atlantic Compact; the compact comprises South Carolina, Connecticut, and New Jersey. South Carolina was originally in the 8-member Southeast Compact that was ratified by the Congress in 1985. However, in 1995, the state withdrew from this compact to become an unaffiliated state primarily because another member of the compact, North Carolina, had failed to develop a new disposal facility as planned by 1992. In 2000, the state joined the Northeast Compact. The name of the Northeast Compact was later changed to the Atlantic Compact to better characterize the geographic affiliation of the three member states. During the history of South Carolina as a compact state and an unaffiliated state, the South Carolina state legislature has only restricted national access to the Barnwell disposal facility for one year, between July 1994 and June 1995, excluding some temporary access restrictions placed on Michigan between 1990 and 1995, and North Carolina between 1995 and 2000.

Three state regulatory entities have roles and responsibilities associated with the operation of the Barnwell disposal facility. The South Carolina Budget and Control Board owns the land that is set aside for the LLRW disposal facility, and it will assume responsibility for the site after it closes. Among other responsibilities, this board approves the disposal rates and authorizes the import of out-of-compact waste to Barnwell. In conjunction with the South Carolina Public Service Commission, the board determines allowable operating costs that can be charged by the operator. The operator is reimbursed for these operating costs and is allowed a 29 percent margin above most of these costs. As South Carolina is an Agreement State (i.e., with the US NRC), the Department of Health and Environmental Control has licensing and technical regulatory authority over Barnwell.

Chem-Nuclear Systems has operated the Barnwell disposal facility continuously since it opened. In 2000, this company became a subsidiary of Duratek, Incorporated, which had purchased the owner of Chem-Nuclear Systems, Waste Management Nuclear Services. According to company officials, there are about 100 Duratek employees at the Barnwell facility, of which 60 to 70 deal with the disposal operations and retain the Chem-Nuclear Systems name. About 10 years ago there were about 350 employees at Barnwell, when disposal intake was higher.

The Barnwell disposal facility is reaching its capacity. About 102 acres of the 235-acre site has been filled, with about 13 acres left for disposal. According to company officials, there is about 2.7 million cubic feet of space remaining. The vast majority of this remaining space, about 2.2 million cubic feet, has been set aside for the decommissioning of the 12 nuclear power plants in the three state compact region. The decommissioning waste is anticipated at about 12,000 cubic feet per facility annually, beginning around 2031 and lasting for about 20 years. Each facility is expected to produce much more LLRW, but much of this waste will likely be shipped to Envirocare of Utah.

The Barnwell disposal facility is planned for closure to out-of-compact waste by mid- 2008. In 2001, the South Carolina legislature imposed volume limits on the amount of waste that could be accepted at Barnwell. Between 2001 and 2008, the facility is allowed to accept decreasing levels of waste until it reaches a steady state level of 35,000 cubic feet in 2008. State officials have stated that the SC legislature set the cap at 35,000 cubic feet to provide revenues sufficient to cover operating costs and all other obligations; however, at current disposal rates, the breakeven volume intake might be as low as 20,000 cubic feet annually. These limits were based on an earlier task force report that provided a “road map’” for discontinuing South Carolina’s national role in providing disposal and ensuring that capacity would remain to serve the future needs of South Carolina generators.

Barnwell has the highest disposal rates among the three commercial disposal facilities. In part, the rates have increased over the years with the additions of special fees, taxes, and surcharges. Non-compact generators have increasingly paid far more to dispose their waste than generators within the compact states, especially South Carolina generators, that receive a 33 percent rebate on their disposal fees. The 2003 rate for compact generators does not exceed about $400 per cubic foot for any class of waste, whereas for non-compact waste coming from processors with importation agreements, it is set at $1,625 per cubic foot. The most sizeable increase in disposal fees came in 1995, when South Carolina imposed a $235 per cubic foot tax on the LLRW accepted by Barnwell. In Current Conditions fiscal year 2002, of the approximately $34 million in gross disposal receipts from waste coming to Barnwell, about $11.6 million went to the operator, and most of the remaining 66 percent went to the state, primarily to support education programs.

Notwithstanding the existing limits on the volume of waste that can be accepted at Barnwell through mid-2008, there are some indications that the legislature may reconsider its position on these limits. First, there has been a shortfall in the volume of waste that has actually come to Barnwell in the last 3 years. Company officials say that this shortfall is 60,592 cubic feet. Negotiations are taking place to determine if this shortfall can be added to the limit levels over the next several years to make up the difference. Second, two utilities that had committed space at Barnwell have decided not to send a reactor vessel and several steam generators to this facility. This would free up even more space, if it were made available. Finally, other space might become available if prior allocation commitments to the 12 nuclear power plants in the Atlantic Compact are revised downward, given changes in how to manage the decommissioning of nuclear power plants. The Electric Power Research Institute is working with utilities on reducing their space needs at Barnwell.

3.5.3.3 Richland, WA

The Richland disposal facility was opened in July 1965. It is situated in Benton County, Washington, approximately 23 miles northwest of the city of Richland, near the center of DOE’s 560 square mile Hanford reservation on 100 of the 1,000 acres of land leased by the State of Washington from the federal government in 1964 for 100 years. The state had hoped to attract other nuclear-related businesses to the site as part of an economic development strategy for the Richland-Kennewick-Pasco region. In 1993, DOE exercised its right under the terms of the lease to reclaim the 900 acres that remained unutilized.

Washington is the current host state for the Northwest Interstate Compact on Low-Level Radioactive Waste Management. Besides Washington, the original members of the compact are Alaska, Hawaii, Idaho, Montana, Oregon, and Utah. The Northwest Compact was established in 1981 and ratified by the Congress in 1985. An eighth state, Wyoming joined the compact in 1992. Also in 1992, the Rocky Mountain Compact, consisting of Colorado, Nevada, and New Mexico, reached agreement with the Northwest Compact and the state of Washington to send up to 6,000 cubic feet of LLRW to the Richland disposal facility annually, plus a 3 percent per annum growth factor. The Northwest Compact did so because the Rocky Mountain Compact expected generation of only a relatively small volume of LLRW once the decommissioning of its only nuclear power plant (Fort St. Vrain in Colorado) was completed. Since 1993, the Richland disposal facility has been open to LLRW only from generators in the 11 states of the Northwest and Rocky Mountain compacts. Regardless of the state of origin, Richland may accept naturally-occurring and accelerator produced radioactive material, which is not addressed by the compact. The Richland facility accepted non-radioactive hazardous and mixed wastes until 1985.

Three state regulatory bodies have roles and responsibilities associated with the operation of the Richland disposal facility: the Department of Health, the Department of Ecology, and the Washington Utilities and Transportation Commission. The Department of Health exercises primary regulatory responsibility over the disposal facility. It issues licenses to the facility operator and regulates radioactive materials. A Department of Health inspector examines each shipment of waste prior to disposal to ensure compliance with the requirements of the U.S.

Department of Transportation, the NRC, and the State of Washington. The Department of Ecology has primary program responsibility. It issues individual permits for radioactive waste disposal to generators, serves as the site landlord, and monitors the activities of the Northwest Compact. The Washington Utilities and Transportation Commission approves the disposal fees on an annual basis. Fees are set at a rate estimated by the facility operator, US Ecology, to produce enough revenue to cover all costs of operating the facility and provide a 29 percent profit. As an integral part of the fee Compact Affiliation State Regulators setting process, the operator polls site users to obtain their projections for how much waste they plan to ship in the coming year. These estimates are the basis on which fees are set.

The private, for-profit contractor, US Ecology Incorporated, a subsidiary of Boise, Idaho-based American Ecology Corporation, and its corporate antecedents, has operated the Richland disposal facility since it opened. According to company officials, there are currently 18 US Ecology employees working at the Richland facility, in addition to 4 administrative staff.

The Richland facility has much unused capacity to accept LLRW. According to state regulators and company officials, the remaining capacity at Richland is approximately 21 million cubic feet. To date the facility has disposed of approximately 13.9 million cubic feet of LLRW in 20 trenches. About 95 percent of the waste received is class A. There has been a significant decline in disposal volumes since 1993, when the Northwest Compact placed restrictions on the origin of the waste that the Richland disposal facility could accept. In the 5 years preceding these restrictions, the average annual amount of LLRW waste disposed was 395,000 cubic feet. In the 11 years since Richland began excluding waste from outside the Northwest and Rocky Mountain Compacts, the average amount of waste disposed annually is about 142,000 cubic feet, though individual years have been as high as 282,000 and as low as 61,000. At the current rates of disposal, fewer than 10 more trenches will be filled, or approximately 60 percent of the total available disposal capacity, when the facility is expected to close in 2056, 7 years before the state lease on the land expires.

Disposal fees and other assorted fees for LLRW or naturally-occurring and accelerator-produced radioactive material waste at Richland are lower than the Barnwell disposal facility, but generally higher than those charged by Envirocare of Utah. Unit costs for disposal are calculated on a declining volume scale. That is, the lower the volume of waste disposed in a given year the higher the unit costs of disposal must be in order to reach the annual, state-approved revenue requirement. Generators pay a number of fees and surcharges to the State of Washington and US Ecology on each cubic foot they dispose at Richland. The state charges a site use permit fee that varies according to volume. For example, fees for waste disposed between March 1, 2004, and February 28, 2005, range from $425 for up to 50 cubic feet to $14,840 for 2,500 cubic feet and more. Nuclear utilities and brokers pay flat annual site use permit fees of $42,400 and $1,000, respectively. The state also imposes other fees and taxes to support local economic development, state agency expenses directly related to the regulation and operation of the facility, and for the Perpetual Care and Maintenance Fund. Unlike the other two commercial LLRW disposal facilities, none of these fees or taxes go directly to the state's general revenue fund. The facility also pays a business and occupation tax.

In addition to the state fees, generators also pay US Ecology's disposal charges, which are based on an annual revenue requirement authorized by the Washington Utilities and Transportation Commission. All LLRW disposed at Richland is assessed charges based on access, volume, shipment(s), container(s), and exposure. For example, based on a projected disposal volume of 50,000 cubic feet of LLRW in 2004 and an annual revenue requirement of approximately $5.4 million, the site operator charges average approximately $108 per cubic foot. The surcharges assessed by the state on disposed waste would generate another $325,000 for local government ($6.50 per cubic foot), $450,000 to cover the regulatory costs of the Washington Department of Health ($9.00 per cubic foot), and at least $230,000 in site use permit fees to cover the regulatory costs of the Washington Department of Ecology and the administrative expenses of the Northwest Compact. The sum of these fees, charges, and surcharges paid by generators to the state and US Ecology in 2004 is expected to total approximately $6.4 million. These associated fees increase the average cost of disposal of LLRW to approximately $128 per cubic foot. This average is calculated based on the expectation that 95 percent of the waste disposed will be class A; typical class B and C waste disposal costs per cubic foot would be higher than this average as activity and other surcharges, which could be considerable, would apply.

There is a strong desire to control the origin, and therefore the volume and nature of the waste disposed at Richland. The State of Washington was a lobbying force behind passage of the regulation that allowed compacts to restrict access to disposal facilities. The state and US Ecology have agreed in concept to a new clause in the sublease agreement, which is expected to be renewed in 2005, providing for termination of the sublease if federal law eliminates the Northwest Compact's restrictive authority on waste importation. This policy is also reflected in the host state agreements with the Northwest Compact and indirectly with the Rocky Mountain Compact. Terminating the sublease would effectively shut down the disposal facility.

3.5.3.4 Envirocare

Since 1988, Envirocare has operated a 540-acre disposal facility 80 miles west of Salt Lake City. The facility is located in Tooele County within a 100-square mile hazardous waste zone that includes two hazardous waste incinerators, the Army's nerve gas storage site, and the Army's Dugway Proving Grounds. Prior to the low-level waste disposal site, DOE used the area for the disposal of uranium mill tailings. Much of the waste disposed at Envirocare comes from cleanup of commercial and government facilities. Also, Envirocare is the only commercial disposal facility to accept mixed waste, which is a combination of radioactive and hazardous waste. In 2003, Envirocare took about 99 percent of the nation's class A waste.

While Utah is part of the Northwest Compact, which includes seven other states, it is not the host state for the compact's LLRW disposal facility. Originally, Utah approved Envirocare's operation for accepting naturally occurring radioactive material—large volume, low activity low-level radioactive wastes. In 1991, recognizing that the Northwest Compact planned to exercise its exclusionary authority at the beginning of 1993, Utah and Envirocare sought a resolution from the Compact that would allow this disposal facility to continue to accept these specific types of low-level waste once the compact exercised its exclusionary authority. [The Low Level Radioactive Waste Policy Amendments Act of 1985 gave compacts the ability to exclude waste outside each compact's regional boundaries.]

Realizing that proposed disposal facilities in other states and compacts were not designed to take wastes of such large volume, the Northwest Compact adopted a resolution and order that allowed continued access to Envirocare by those states that met the milestone requirements of the Act. [e.g., One milestone, for example, set a deadline of January 1, 1992, for states and compacts to submit a license application for disposal facilities in their respective regions. Another milestone required that if a state did not have a viable disposal facility by January 1, 1996, a state or state(s) in a compact must take title to the waste when requested by generators. However, in 1992, the U.S. Supreme Court ruled that this provision was unconstitutional. [New York v. United States, 505 U.S. 144 (1992).]

In 1995, the resolution and order were amended to include a provision that states and compacts in which low-level waste is generated, including the Northwest Compact, must authorize any shipment of this waste to Envirocare. This was done to ensure that states and compacts maintain control over the disposition of LLRW generated within their state or compact. The resolution and order was also amended to delete the provision regarding the statutory milestone requirements since those milestones were no longer relevant. According to the executive director of the Northwest Compact, the compact retains the right to modify or rescind this authorization at any time. In 1998, Utah issued a license amendment for Envirocare to accept all types of class A low-level waste. To date, the Northwest Compact has not approved sending LLRW generated within the compact states, including Utah, to the Envirocare disposal facility.

The Utah Department of Environmental Quality has licensing and regulatory authority for the Envirocare facility. Envirocare's license has been amended at least 10 times to allow more types of radioactive waste including in 1991 when the state permitted disposal of low-level waste, in 1995 when Envirocare became the only commercial disposal facility licensed for mixed waste, and in 2001 when Utah approved an amendment for Envirocare to accept all types of class A waste.

[Allowing all types of class A waste includes containerized class A waste, which is shipped, received, and disposed in remotely-handled sealed containers. By contrast, bulk waste is generally removed from its shipping containers and is "contact-handled" in a process that typically involves compacting the waste in 12-inch layers over the disposal area. Unlike the Barnwell and Richland commercial disposal sites, waste at Envirocare is placed in broad, shallow cells that are designed to finish above-grade. These disposal cells are constructed using native clay and rocks as liner and cap materials.]

On July 9, 2001, the Utah Department of Environmental Quality approved Envirocare's license application to accept Class B and C wastes. Appeals were filed and on February 10, 2002, the department affirmed the approval. In March 2003, the Governor of Utah signed a bill placing a moratorium on any acceptance of Class B or C wastes through February 15, 2005, and requiring legislative and gubernatorial approval for acceptance of these wastes. Enactment of the bill also created a task force composed of 16 state legislators to study radioactive waste, hazardous waste, and commercial solid waste issues in the state, including state policy and an evaluation of fees and taxes imposed on these wastes. The task force was required to issue a report with specific recommendations by November 30, 2004, on, among other things, whether the state should accept Class B and C wastes. A joint legislative task force recommended in October 2004 to maintain the moratorium on Class B and C waste, but failed to call for an all-out ban. In early 2005, the governor of Utah, top officials of both houses of the Legislature from both political parties and Envirocare's new owners, all supported banning disposal of Class B and C wastes. A bill was subsequently passed by the state senate that imposed a ban on both of these classes of waste.

Envirocare, a privately owned company, has operated the disposal facility since its inception in 1988. The company said it has about 400 employees and about 250 employees are directly involved with low-level radioactive waste operations. Unlike the Barnwell and Richland sites, Envirocare owns the disposal site land. NRC normally requires institutional ownership of disposal sites in post-closure. According to NRC, Utah exempted Envirocare from the requirement that the federal or state government own the disposal site land. However, at the inception of a license for the disposal facility in Utah the state's Department of Environmental Quality established a national precedent when it exempted the site from rules requiring institutional ownership. At the time, Utah regulations contained a section compatible with NRC's rule that disposal from other persons would be permitted only on land owned by the federal or state government. Nevertheless, Utah did not have legislative authority to own land used for disposal of LLRW. While the private entity is allowed to own the land indefinitely, the state requires that Envirocare carry a surety fund, currently about $40 million for low level and other wastes, for eventual site closure, decommissioning, and long-term stewardship. Utah will receive the funds if Envirocare should become unable to perform site closure and decommissioning.

The disposal site has the capacity for more than 20 years of disposal under its current license. According to Envirocare officials, at the beginning of March 2004 the disposal facility had 58.9 million cubic feet of class A waste. The officials anticipate that the disposal facility will accommodate more than 20 years of waste for several reasons, such as a reduction in the annual disposal of waste at Envirocare.

Envirocare typically has a contract condition requiring that its commercial disposal rates not be disclosed. While disposal rates are available for DOE waste, they are not reflective of disposal rates for other LLRW generators. According DOE officials, DOE receives a more favorable disposal rate than generally available to other LLRW generators because DOE can obtain discounted rates from Envirocare given the large volumes of waste it has for disposal and that it can use its own disposal facilities. DOE represents more than half of Envirocare's business. DOE's contract with Envirocare, which expired June 29, 2004, includes disposal rates ranging from a minimum of about $5.25 per cubic foot for soil to a minimum of about $14.80 per cubic foot for debris. [The contract has 4 additional option years. New contacts and revisions may require that additional taxes be included.] Most DOE waste is shipped to Envirocare in bulk containers. According to DOE officials, Envirocare's rail access and closer proximity to DOE sites east of Utah provide a disposal cost advantage over using DOE disposal facilities.

Envirocare is subject to fees and taxes on waste disposal. The legislature raised fees and taxes in 2003 after a citizens' initiative to substantially increase the fee and tax structure failed. The state levies a fee of 15 cents per cubic feet of waste and $1 per curie for radioactive waste. These funds are used to offset program costs for oversight. In addition, each generator pays a fee to the state ranging from $500 to $1,300 for a generator site access permit. These funds as well as a $5,000 fee paid by each broker are for state oversight of the disposal facility. In addition, the state imposes a fee ranging from 5 percent to 12 percent of gross receipts of the disposal operator as general tax revenue to be used in a manner determined by the state legislature. The amount is based on the type of waste and whether the source is from a government or nongovernmental generator. In addition, as of 2002, Envirocare is required to pay the state a perpetual care fee of $400,000 per year. Also, Tooele County imposes a 5 percent fee on the operator's gross receipts. In recent years the operator has provided the county about $4 million annually. Those funds are general tax revenue for the county. According to the disposal operator, on average, Envirocare provides 25 percent of the county's budget. Figure 5 shows the rail unloading facility for disposal of class A bulk waste at the Envirocare facility.

3.5.4 Inventories, conditioning and disposal strategies for existing HTR waste

3.5.4.1 Peach Bottom 1

Peach Bottom operated from June 1967 until it was permanently shutdown in October 1974. It is currently in a SAFSTOR condition. All of the graphite fuel has been removed from the site but the graphite components within the reactor vessel still remain. Final decommissioning is not expected until 2034 when two LWR units on the same site are scheduled to shut down. The Peach Bottom 1 spent fuel was shipped to the US DOE Idaho National Environmental and Engineering Laboratory (INEEL) for temporary storage. The US DOE Office of Environmental Management notes that there are 1603 "Fuel handling Elements" from the Peach Bottom 1 Reactor that will be eventually transferred to a Modular Vault Dry Storage facility to be constructed and operated at INEEL by the Foster Wheeler Environmental Corporation. Eventually, the Peach Bottom 1 spent fuel will be loaded into a specialized container designed for emplacement into Yucca Mountain. There is a total of about 26 metric tons of graphite fuel at INEEL which includes Fort St Vrain and Peach Bottom 1 Fuel.

3.5.4.2 Fort St. Vrain

The FSV reactor has been fully decommissioned. FSV reflector block and structural graphite was disposed of as LLW at the Northwest Compact Facility in Richland WA. Part of the spent FSV fuel elements (1464) are in storage either at FSV in an Independent Spent Fuel Storage Installation (ISFSI). The remaining 738 FSV fuel elements are stored intact at the Idaho

National Laboratory. All spent FSV fuel will be ultimately sent to Yucca Mountain for disposal. However, the final disposal form has not been decided (i.e., whole block or fuel compacts only).

3.5.4.3 Defense Reactor

There were also a number of plutonium production and other types of reactors that operated at various Government-owned sites in the U.S. Of the 14 Government production reactors, many were moderated with graphite (Hanford - 8) and others were moderated with heavy water (Savannah River). The Hanford N- reactor which was a combination plutonium production reactor and electricity generator had a graphite-moderated core and was water cooled. Although the weight of the graphite moderator was unavailable, the N-Reactor core is made of graphite and measures 39 by 33 by 33 feet. A decision has not been reached on the disposal of the N-Reactor. However, the other eight Hanford reactors will each be moved as a single unit from their existing sites near the Columbia River, temporarily stored on higher ground, and ultimately be buried in a massive pit prepared especially for their disposal near the center of the Hanford site.

In addition to the Hanford reactors, other graphite moderated reactors operated at several of the US National Laboratories. An example is one that operated at Brookhaven National Laboratories. The reactor pile consisted of a 700-ton, 25-foot cube of graphite fuelled by uranium.

There are approximately 55,000 tons of irradiated graphite in the US that require disposition.

4 International Classification Schemes

4.1 IAEA recommendations

The IAEA have recognised the difficulties arising from the existence of a distinct number of differing national schemes for classifying radioactive waste, and the subsequent difficulties with communication regarding waste management practices and general problems in comparing published data. A method of deriving a general system for classifying radioactive waste was therefore recommended by the IAEA in 1994 [35]. The system does not provide rigourous boundaries between the suggested categories, but provides a general framework and recommendations for specfic schemes based on generally applicable principles. The general system takes into account the manangement and disposal routes for the waste, and is summarised below.

4.1.1 Exempt waste (EW)

Exempt waste is defined as that which contains so little radioactive material that it cannot be considered 'radioactive' and might be exempt from nuclear regulatory control. Although still radioactive from a physical point of view, this waste may be safely disposed of, applying conventional techniques and systems, without specifically considering its radioactive properties. The IAEA provides recommendations on exemption from regulatory control and specifies unconditional clearance levels for radionuclides in solid materials based on limiting annual doses to members of the public to 0.01 mSv. The recommended activity concentrations are dependent on the individual radionuclide and range from about 0.1 Bq/g to about 104 Bq/g. Because possible individual radiation doses are trivial at these concentrations, no particular attention needs to be paid to the radioactive properties of such waste.

4.1.2 Low and intermediate level waste (LILW)

Low level waste has previously been defined by the IAEA as radioactive waste that does not require shielding during normal handling and transportation. Waste which required shielding but needed little or no provision for heat dissipation was classified as intermediate level waste. A contact dose rate of 2 mSv/h was generally used to distinguish between the two classes. The classification is now based upon activity levels and half-lives of individual radionuclides and the terms ‘short-lived waste’ and ‘long-lived waste’ are defined by the IAEA as follows :

4.1.2.1 LILW-SL

Short-lived waste is radioactive waste which will decay to an activity level which is considered to be acceptably low from a radiological viewpoint, within a time period during which administrative controls can be expected to last. Radionuclides in short-lived waste will generally have half-lives shorter than 30 years. This waste may be disposed of in near surface or deep geological facility if co-disposed with long-lived waste.

4.1.2.2 LILW-LL

Long-lived waste is radioactive waste containing long-lived radionuclides having sufficient radiotoxicity in quantities and/or concentrations requiring long term isolation from the biosphere. Long-lived radionuclides usually have half-lives greater than 30 years. This waste may be disposed of in a deep geological facility.

The IAEA does not give a general boundary between near surface and geological disposal of radioactive waste, as activity limitations will differ between individual radionuclides or radionuclide groups and will be dependent on the actual planning for a near surface disposal facility (e.g. engineered barriers, duration of institutional control, site specific factors). However the IAEA recommends the following criteria for near surface disposal facilities:

- an overall average limit of about 400 Bq/g for long-lived alpha emitters in waste packages
- limits for long-lived beta and gamma emitting radionuclides to be based on analyses of each specific disposal facility.

4.1.3 High Level Waste (HLW)

High level waste is defined as that which contains large concentrations both of short and long lived radionuclides, so that a high degree of isolation from the biosphere, usually via geological disposal, is needed to ensure disposal safety. It generates significant quantities of heat from radioactive decay, and normally continues to generate heat for several centuries.

An exact boundary level is considered by the IAEA as difficult to quantify without precise planning data for individual facilities. Specific activities for these waste forms are dependent on many parameters, such as the type of radionuclide, the decay period and the conditioning techniques. Typical activity levels are in the range of 5×10^4 to 5×10^5 TBq/m^3, corresponding to a heat generation rate of about 2 to 20 kW/m^3 for decay periods of up to about ten years after discharge of spent fuel from a reactor. From this range, the lower value of about 2 kW/m^3 is considered reasonable to distinguish HLW from other radioactive waste classes, based on the levels of decay heat emitted by HLW such as those from processing spent fuels.

4.2 EU Classification Scheme

The classification systems for radioactive waste in use across individual European countries vary widely in approach and application. Some are used purely for communication purposes, while others are dictated by the disposal route. The different radioactive waste classification systems are based on activity concentration, total activity, waste source or disposal route. Differences in radioactive waste classifications are considered by the EU to make it difficult to optimise disposal facilities and to transport wastes between member states following treatment and/or conditioning.

To address this situation, in 1999 the EU ratified a common classification system for radioactive wastes [35], and from 2002 this has been used for high level reporting of waste inventories to the EU. The scheme is based closely upon the guidance for classification schemes provieded by the IAEA, which is reviewed in Section 4.1.

In the EU scheme, two basic categories of materials are defined

1. those materials that can be managed outside of the regulatory control system

2. those residual materials for which no further use is foreseen and which need specific management procedures according to their radioactive properties

Only category 2 materials are regarded by the EU scheme as 'radioactive waste' for which two basic management alternatives are defined:

1. Storage for a limited period of time until they can either be assigned to category 1 or disposed;
2. Disposal following well-established routes (surface, near-surface, or deep disposal).

The EU classification system has four levels as follows :

4.2.1 Transition radioactive waste

Type of radioactive waste (mainly from medical origin) which will decay within the period of temporary storage and may then be suitable for management outside of the regulatory control system subject to compliance with clearance levels. It is suggested to use five years as the maximum duration, beyond this period of five years the waste should be regarded as low and intermediate level waste.

4.2.2 Low and intermediate level waste (LILW)

LILW is defined as that in which the concentration of radionuclides is such that generation of thermal power during its disposal is sufficiently low. These acceptable thermal power values are site-specific following safety assessments.

4.2.2.1 Short-lived waste (LILW-SL)

Short-lived waste is radioactive waste which will decay to an activity level which is considered to be acceptably low from a radiological viewpoint, within a time period during which administrative controls can be expected to last. Radionuclides in short-lived waste will generally have half-lives shorter than 30 years. This waste may be disposed of in near surface or deep geological facility if co-disposed with long-lived waste.

This category includes radioactive waste with nuclides within half-life less than or equal to those of Cs137 and Sr90 (around 30 years) with a restricted alpha long-lived radionuclide concentration (limitation of long-lived alpha emitting radionuclides to 4000 Bq/g in individual waste packages and to an overall average of 400 Bq/g in the total waste volume).

4.2.2.2 Long-lived waste (LILW-LL)

Long-lived radionuclides and alpha emitters whose concentration exceed the limits for short-lived waste.

4.2.3 High level waste (HLW)

Waste with such a concentration of radionuclides that generation of thermal power shall be considered during its storage and disposal. (The thermal power generation level is site-specific and this waste is mainly forthcoming from treatment/conditioning of spent nuclear fuel).

From 2002, each country in the EU is required to report national waste inventories using the EU classification scheme.

5 Conclusions

5.1 Identification of common denominators

A comparison of the radioactive waste classification schemes and disposal routes reviewed in Section 3 reveals many converging criteria, but also some significant areas of difference between the national schemes. The schemes are summarised and compared in Table 9.

Amonst the EU states, the Belgian and French schemes are very similar and are closely related to the EU classification scheme, which is in itself based upon the generic IAEA recommendations. These schemes formally recognise the lifetimes of the predominant radionuclides within waste packages, and segregate low and intermediate level waste into short-lived and long-lived categories, on the basis of whether the half-lives of these nuclides are less-than or greater-than 30 years respectively. These correspond to the EU LILW-SL and LILW-LL categories, and are linked to the planned disposal routes. EU LILW-SL, Belgian Category A waste, and French short-lived LLW and ILW are all suited to surface disposal, whereas EU LILW-LL, Belgian Category B waste, and French HLW and long-lived ILW will require geological disposal.

The Belgian scheme formally quantifies the division between short-lived (Category A) and long-lived (Category B) waste on the basis of a concentration criterion (Criterion X – Section 3.1.2.1) which indentifies maximum volumetric activity concentrations for a set of key long-lived nuclides. A second criterion (Criterion Y) which assesses waste activity against the total radiological capacity of the disposal site is also applied.

The French scheme distinguishes betweeen low-level and intermediate level long-lived waste, and places graphite waste into the former of these categories, for which a dedicate disposal facility is planned. The lower limit for High Level Waste is defined on the basis of volumeteric decay power generation in the Belgian scheme, which requires waste with decay power densities in excess of 20 W/m^3 to be classified as Category C waste. This is roughly equivalent to the activity-based limit in the French scheme of 10^8 Bq/g.

The French and Belgian schemes, and the EU scheme upon which they are based therefore classify waste according to the planned disposal route for package waste items, and make a direct link between the properties of the waste package and the acceptance criteria of the disposal route (ie Belgian ‘Criterion Y’).

The UK classification scheme is not directly related to the disposal route, and does not address the half-lives of the constituent radionuclides in the same manner as the other EU schemes reviewed. An activity criteria is used to categorise wastes as low-level waste and intermediate level waste whereas the EU scheme uses a lifetime criteria to divide these wastes into short-lived (LILW-SL) and (LILW-LL). The EU scheme, and those of Belgium and France are based upon packaged waste items, whereas the UK scheme classifies waste on the basis of its raw characteristics prior to packaging and without reference to the disposal route. On this basis, additional site-based conditions for acceptance are enforced at the UK surface disposal facility at Drigg, and low/intermediate level graphite waste from conditioned HTR fuel would have to be assessed against these limits. There is no disposal route for ILW in the UK, although there are activities in progress to produce a short-list of options and recommendations for further study and investigation, so it is not possible to anticipate the acceptance criteria for any eventual facilty.

The German classification scheme for disposal is not in accordance with the other EU states because Germany has decided to dispose of all kinds of radioactive waste in deep geological repositories. No distinction is therefore required between low-level, medium-level and high-level waste, or between long lived and short lived radionuclides (however such a classification is still used by the waste producers for practical reasons during handling). A basic classification is made between heat generating and negligible heat generating waste.

Negligible heat generating wastes are defined as those wastes which have a negligible thermal effect upon the surrounding host rock. This is defined as a temperature increase below 3K in case of the Konrad mine, which is proposed as a repository for negligible heat generating waste. Site acceptance criteria, including maximum nuclide inventories will be derived from a safety analysis specific to the disposal site, which will leads to requirements with respect to the waste packages and waste forms. In particular, the maximum disposable nuclide inventory for ^{14}C will cause problems for the ceramic waste arising from dismantling of the two German high temperature reactors AVR and THTR, because the ^{14}C inventory of these ceramics would utilise nearly the whole amount of ^{14}C licensed for the Konrad repository.

Furthermore spent fuel is excluded from the group of negligible heat generating wastes, even if the spent fuel would meet this criterion after an extended cooling period. Therefore all spent fuel obtained during operation of AVR and THTR are designated for a repository considered for heat generating waste.

The US commercial radioactive waste classification system has four categories of waste recognised by the USDOE, and six levels adopted for the classfication of commerical waste, which can to some extent be mapped onto the IAEA system. In a similar manner to the UK scheme, the US scheme categorises waste on the basis of its origin and characteristics.

Having made a comparitive review of several national classification systems, it is apparent that the EU scheme, which is itself an implementation of IAEA recommendations, forms a useful basis for discussing HTR spent fuel disposal within the context of the RAPHAEL-BF Sub-project, as it directly relates packaged waste characteristics to those of the disposal route. Whilst the UK scheme does not preempt the disposal route, and relies on additional site-based conditions for acceptance, it is less useful for providing a framework for discussing the generic disposal routes for waste arisings from HTRs.

5.2 Specifications for disposal of future HTR waste

As previously stated, EU states will have to report national waste inventories using the EU classification scheme, so it is proposed to discuss and define HTR waste management principles in the context of this scheme. This can then be mapped onto the individual national schemes as required.

The review performed in this document has confirmed that disposal routes for waste containing radionuclides with half-lives in excess of 30 years, and waste with significant decay heat generation, corresponding to EU categories LILW-LL and HLW respectively, are not well established in some EU states eg UK, Germany but likely to converge on the same common denominators for geological disposal. The US scheme differs from the EU scheme, but can be mapped onto the IAEA scheme, and is partly based around the identification of Yucca Mountain as a final disposal site.

Untreated spent HTR fuel from a commercial power reactor will contain high initial concentrations of long-lived radionuclides and high levels of decay heat output and will therefore be classified as HLW in the EU scheme, and direct disposal will be the only disposition route available. A detailed study of the engineered barrier systems, beginning with the TRISO coating containtaing the fission products, and extending to the graphite matrix and the packaging container will be required, alongside that of the respository design, in order to determine acceptance critiera for spent HTR fuel.

If HTR fuel is reprocessed, it will be separated into consituent components, which will comprise block graphite and compacts, depending on the back-end treatment path followed. The disposal strategy that can be adopted for these constituents is imposed by the radiological characteristics and thermal output of the conditioned waste, and so these characterisics must be determined in more detail by the RAPHAEL-BF programme. The waste packages arising can be disposed in a surface repository only on the condition that concerned waste packages complies with the criteria equivalent to those for EU LILW-SL. For conditioned reprocessed HTR waste which belongs to EU LILW-LL or HLW, geological disposal is the only available strategy.

Table 9 - Summary and comparison of radioactive waste classification schemes

Belgium	France	EU	IAEA	UK	Germany
	VLLW - <100 Bq/g	Transition Waste	EW – Exempt waste	VLLW - less than 400 kBq of beta/gamma activity per 0.1 m^3 material	Waste with negligible heat generation
Cat A - low concentrations short half-lives (Criteria X and Y)	LLW Short-lived - half-lives < 30 years Activity between 100 and 10^5 Bq/g - - - - ILW Short-lived - half-lives < 30 years Activity between 10^5 and 10^8 Bq/g	LILW-SL Short-lived, half-lives < 30 years	LILW-SL Short-lived, half-lives < 30 years	LLW - < 4 GBq/te of alpha and <12 GBq/te of beta/gamma activity	
Cat B - medium or long half-lives in relatively high concentrations. power <20W/m^3	LLW Long-lived - half-lives > 30 years Activity between 100 and 10^5 Bq/g - - - - ILW Long-lived - half-lives > 30 years Activity between 10^5 and 10^8 Bq/g	LILW-LL Long-lived, half-lives > 30 years	LILW-LL Long-lived, half-lives > 30 years	ILW - > 4 GBq/te of alpha or >12 GBq/te of beta/gamma activity, no heating consideration in storage facilities	Heat generating waste
Cat C - substantial amounts of beta and alpha emitters Power >20 W/m3.	HLW Activity between 10^8 and 10^{10} Bq/g	HLW	HLW	HLW – As ILW and with cooling in storage facilities	

USA
Spent Nuclear Fuel
High Level Waste (HLW): Similar to European definitions; arises mainly from manufacture of nuclear weapons
Transuranic Waste (TRU): radioactive waste containing more than 100 nCi/g of alpha-emitting transuranic isotopes with half-lives greater than 20 years nuclear weapons
Uranium mill tailings
Naturally occurring radioactive material
Low-Level Radioactive Waste (LLW): by definition: everything else

Generic Disposal Routes

Landfill / Free Disposal
Surface Disposal
Geological Disposal

6 References

1. Generation IV Nuclear Energy Systems Initiative Fact Sheet
   Office of Nuclear Energy, Science and Technology,
   U. S. Department of Energy
   February 2005

2. HTR-N Technical Summary Report of WP4 – Specific Wastes
   J Fachinger, J Turner, A Nuttall, C Bourdeloie, G Brinkmann, H Bruecher, W Von Lensa
   Novemeber 2004
   HTR-N-04/11-D-4.0.4

3. Current status and future development of modular high temperature gas cooled reactor technology, Chapter 8 - HTGR Spent fuel and decommissioning
   IAEA-TECDOC—1198
   February 2001

4. *"Institutional framework for long term management of high level waste and/or spent nuclear fuel"*. International Atomic Energy Agency, IEAE-TECDOC-1323, December 2002, 161 pp.

5. RD-1981. Royal Decree of 30 March 1981. Arrête royal réglant l'agrément d'équipements destinés à l'entreposage, au traitement et au conditionement de déchêts radioactifs. Royal Decree dated 30th March 1981. Published in the Moniteur Belge on 5 May 1981. Royal Decree stipulating the competences and modalities of operation of NIRAS/ONDRAF. *Koninklijk besluit van 30 maart 1981 (B.S. 5/5/81) houdende bepaling van de opdrachten en de werkingsmodaliteiten van NIRAS.*

6. L-1994. Law of 15 April 1994 concerning the protection of the population and of the environment against the dangers from ionising radiations and concerning the Federal Agency for Nuclear Control. *Wet van 15 april 1994 betreffende de bescherming van de bevolking en van het leefmilieu tegen de uit ioniserende stralingen voortspruitende gevaren en betreffende het Federaal Agentschap voor Nucleaire Controle*

7. RD-2001. Royal Decree of 20 July 2001 (RD-2001). *Arrête royal portant mise en vigueur de la loi du 14 avril 1994 relative à la protection de la population et l'environment contre les dangers résultant des rayonnements ionisants et relative à l'Agence fédérale de controle nucléaire. Royal Decree dated 20th July 2001.* Published in the Moniteur Belge on 30.08.2001.

8. *Report of the Kingdom of Belgium to the "Third Meeting of the Contracting Parties to the Convention on Nuclear Safety"*. National Report. September 2004. Report submitted by the Federal Agency for Nuclear Control on behalf of Belgium (with contributions by the 'Association Vinçotte Nucléaire' and ELECTRABEL. 135 pp.

9. SL-1980. Special Law of 8 August 1980 on Institutional Reforms. Law concerning the budgetary proposals 1979-1980. (Wet van 8 augustus 1980 betreffende de budgettaire voorstellen 1979-1980.) Published in the Moniteur Belge on 15 August 1980. Article 179 regulates the establishment of NIRAS/ONDRAF. *Wet van 8 augustus 1980 (verschenen in het Belgisch Staatsblad op 15 augustus 1980): bijzondere wet tot hervorming der instellingen die NIRAS opricht (artikel 179 § 2)*

10. L-1991. Law of 11 January 1991 replacing article 179 paragraph 2 of the SL-1980. Published in the Moniteur Belge on 12 February 1991. *Wet van 11 januari 1991 (B. S. 12/2/91) ter vervanging van artikel 179 § 2 van de wet van 8 augustus 1980;*

11. RD-1991. Royal Decree of 16 October 1991. Published in the Moniteur Belge on 22 November 1991. Royal Decree modifying the RD-1981. *Koninklijk besluit van 16 oktober 1991 (B. S. 22/11/91) houdende wijziging van het koninklijk besluit van 30 maart 1981;*

12. PL-1997. Programme Law of 12 December 1997 including various stipulations extending the competences of NIRAS/ONDRAF to the inventory of the 'nuclear liabilitries'. Published in the Moniteur Belge on 18 December 1997. *Programmawet van 12 december 1997 (B. S. 18/12/97) houdende diverse bepalingen die de opdrachten van NIRAS uitbreidt tot de inventaris van de "nucleaire passiva" (artikel 9))*.

13. RD-2000. Royal Decree of 31 May 2000 concerning the settlement of the contributions for the establishment and the maintaining of the inventory of 'nuclear liabilities'. Published in the Moniteur Belge on 27 July 2000. *Koninklijk besluit van 31 mei 2000 (B. S. 27/7/2000) houdende vaststelling van de bijdragen voor het opstellen en bijhouden van de inventaris van de "nucleaire passiva"*.

14. NIROND 94-04. De oppervlakteberging op Belgisch grongebied van laagactief afval en afval met korte halveringstijd: synthese en aanbevelingen. Report NIRAS/ONDRAF, April 1994

15. NIROND 2005-01. Syntheserapport impactevaluaties voor oppervlakteberging van categorie A afval te Mol en Dessel. Report NIRAS/ONDRAF, April 2005

16. Gesetz über die friedliche Verwendung der Kernenergie und den Schutz gegen ihre Gefahren (Atomgesetz - AtG) vom 23. Dezember 1959, Neufassung vom 15. Juli

1985 (BGBl. I, Nr.41), zuletzt geändert durch Gesetz zur Kontrolle hochradioaktiver Strahlenquellen vom 12. August 2005 (BGBl. I S. 2365)

17. Verordnung über den Schutz vor Schäden durch ionisierende Strahlen (Strahlenschutzverordnung - StrlSchV) vom 20. Juli 2001 (BGBl. I 2001, Nr.38), zuletzt geändert durch Gesetz zur Kontrolle hochradioaktiver Strahlenquellen vom 12. August 2005 (BGBl. I S. 2365)

18. Bundesberggesetz i.d.F. vom 13. August 1980 (BGBl. I S. 1310), zuletzt geändert durch Gesetz vom 19. Juli 2002 (BGBl. I 2002, Nr.50)

19. Verordnung über Vorausleistungen für die Einrichtung von Anlagen des Bundes zur Sicherstellung und zur Endlagerung radioaktiver Abfälle (Endlagervorausleistungsverordnung - EndlagerVlV) vom 28. April 1982 (BGBl. I, S. 562), zuletzt geändert durch VO vom 26. Juli 2004 (BGBl. I 2004, Nr.33)

20. Verordnung über den Schutz vor Schäden durch Röntgenstrahlen (Röntgenverordnung - RöV) vom 8. Januar 1987 (BGBl. I S. 114), zuletzt geändert durch Art. 11 der Verordnung für die Umsetzung von EURATOM-Richtlinien zum Strahlenschutz vom 20. Juli 2001 (BGBl. I S. 1714, 1845)

21. State and Development of Nuclear Energy Utilization in the Federal Republic of Germany 1997, English version of report BfS-KT-21/98, April 1998 (Stand und Entwicklung der Kernenergienutzung 1997 in der Bundesrepublik Deutschland)

22. Anforderungen an endzulagernde radioaktive Abfälle (Vorläufige Endlagerungs-bedingungen, Stand: April 1990 i.d.F. Oktober 1993), Schachtanlage Konrad, BfS-Report ET-3/90-REV-2 (1993)

23. Vereinbarung zwischen der Bundesregierung und den Energieversorgungs-unternehmen vom 14. Juni 2000 (Agreement between the Federal Government and the Electricity utilities from June 14, 2000) http://www.bmu.de/files/pdfs/allgemein/application/pdf/atomkonsens.pdf

24. Conceptual and Safety-related Technical Questions Associated with the Final Storage of Radioactive Waste. A Comparison of Types of Host Rock. http://www.bfs.de/endlager/publikationen/Einzelfragen_Endlagerung.html

25. Radioactive Substances Act 1993 (c. 12), ISBN 0105412937

26. The 2004 UK Radioactive Waste Inventory
Defra Report DEFRA/RAS/05.002, Nirex Report N/090
October 2005

27. Managing the Nuclear Legacy - A Strategy for Action
House of Commons Publication Cm. 5552, July 2002

28. Our energy future - creating a low carbon economy
House of Commons Publication Cm. 5761, February 2003

29. Managing Radioactive Waste Safely - Proposals for developing a policy for managing solid radioactive waste in the UK
Department for Environment, Food and Rural Affairs, September 2001

30. UK Classification System
G Turner, Nirex, April 2002

31. Identification and Description of UK Radioactive Wastes and Materials Potentially Requiring Long-term Management
United Kingdom Nirex Limited, Nirex Report no. N/085, July 2003

32. Conditions for Acceptance by BNFL of Radioactive Waste for Disposal at Drigg (CFA) Issue 2/01
J. P. Storer, BNFL, October 2002

33. HTR Specific Wastes – Assessment of the Advantages of Graphite Treatment
L Walker, NNC Ltd
HTR-N-05/05-D-4.4.1
January 2004

34. How should the UK manage radioactive waste? 2nd Consultation Document, 4th April to 27th June
Committee on Radioactive Waste Management

35. Classification of Radioactive Waste - A Safety Guide
IAEA Safety Series No. 111-G-1.1

36. Commission Recommendation of 15 September 1999 on a classification system for solid radioactive waste
1999/669/EC, Euratom
Official Journal of the European Communities, 13th October 1999