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Integrated Waste Management Approach WP 1 Review Report – Germany

Executive summary

Two helium-cooled high temperature pebble bed reactors have been built and operated in Germany. The AVR, a 15 MWe experimental reactor at Juelich was shut down in 1988 after 21 years of operation. The 300 MWe prototype Thorium High Temperature Reactor THTR was operated from 1985 until 1989 in Hamm-Uentrop. Both reactors are now permanently shut down and are at different stages of decommissioning.

The moderator graphite is an integral part of the spherical fuel elements of AVR and THTR. Until the end of the seventies a closed fuel cycle concept with reprocessing of the thorium-based spent fuel - similar to the U.S. - was developed in Germany. It included mechanical disintegration of the fuel elements, incineration of the moderator graphite, and recovery of the fissile material from the fission products by extraction. In early 1980 the Government decided to stop R&D on reprocessing mainly due to economical reasons. Since then, the back-end option for the spent fuel is based upon direct disposal in a deep repository without reprocessing, thus using the special safety features of the fuel elements, i.e. the coated particle fuel stabilised in a graphite matrix, which is extremely resistant against all conceivable attacks during storage and geological disposal.
The spent fuel elements were removed from both reactors and are stored in CASTOR-type transport/storage casks in dry interim storage facilities on-site (at Juelich for the AVR) and at Ahaus (for the THTR) for up to 30 years, until a deep geological repository will be available.

Graphite and low-purity carbon were used in both reactors for reflector, thermal insulation and shielding purposes, amounting to 225 Mg (AVR) of ceramic materials in total and about 550 Mg in case of the THTR. A radiochemical characterisation of the AVR ceramic materials was performed, leading e.g. to carbon-14 levels between 100 kBq/g for graphite and 9 MBq/g in maximum for low-purity carbon.

There is also a limited amount of graphite (reflectors, thermal columns) with low activation from water-moderated research and material test reactors in Germany.
A 10 MW research reactor (Merlin type) with two thermal columns was operated at Juelich for 23 years and decommissioned to greenfield. 11 Mg of irradiated graphite with a medium carbon-14 activity of 71 Bq/g are being stored at Juelich waiting for disposal.
A 23 MW heavy-water material test reactor (DIDO) was operated at Juelich for 45 years and shut down in 2008. The irradiated graphite from reflector and thermal columns amounts to 30 Mg. Radiological analyses are in preparation.

Revisions

Rev.	Date	Short description	Author	Internal Review	Task Leader	WP Leader
01	30/04/2008	First issue	von Lensa FZJ		H Eccles (UK NNL)	H Eccles (UK NNL)
02	12/06/2008	2nd Issue	von Lensa FZJ		H Eccles (UK NNL)	H Eccles (UK NNL)

Chapter contents

1 Introduction

This chapter describes the graphite waste management challenges for Germany. Nearly twenty NPPs are in various stages of decommissioning and a further, nearly, forty research reactors decommissioned or being decommissioned (28 dismantled). It is not clear how many of these reactors produced noticeable quantities of i-graphite. The chapter largely concentrates on two helium-cooled pebble bed reactors the AVR, a 15 MWe experimental reactor at Juelich and a larger (300 MWe) prototype thorium high temperature reactor (THTR) in Hamm –Uentrop. Both are now permanently shut down and are at different stages of decommissioning.

Pebble bed type reactors present unique i-graphite waste management challenges, additional to those of the Magnox, UNGG and RBMK type reactors. This is reflected in the i-graphite characteristics and other considerations such as retrieval and treatment.

2 The legislative and regulatory framework

The interaction of the different authorities and organisations involved in the nuclear licensing procedure is shown in Figure 1.

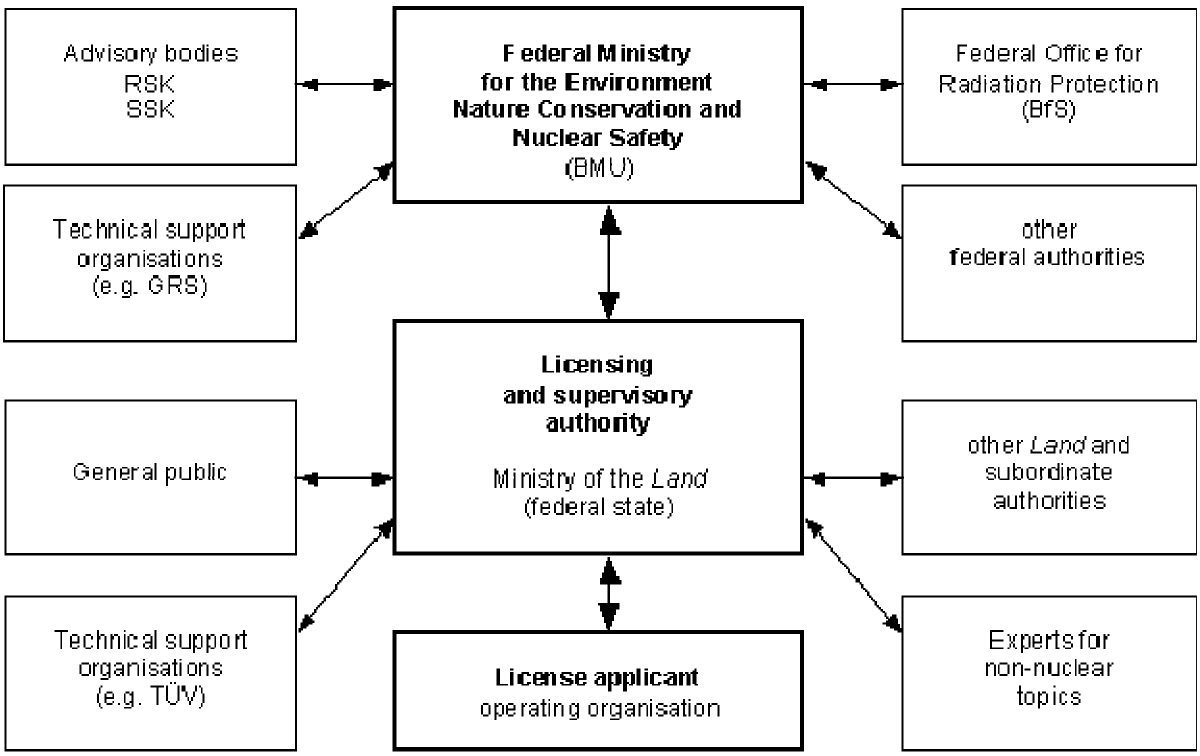

Figure 1: Nuclear licensing authorities and organisations[1]

The Atomic Energy Act, adopted on 23 December 1959, as amended by the 2002 Act. The consolidated text of the 2002 Act is reproduced in the Supplement to the OECD Nuclear Energy Agency's Nuclear Law Bulletin 70. The Atomic Energy Act is the core of national regulations in Germany. Its primary purpose is to protect life, health and property against the hazards of nuclear energy and the detrimental effects of ionising radiation, and furthermore, to provide for compensation for any damage and injuries incurred. According to the amendment of 2002, another purpose is to phase out the use of nuclear energy for commercial electricity production.

The 1986 Act on Preventive Protection of the Public against Radiation. The text of the Act is reproduced in the OECD Nuclear Energy Agency's Nuclear Law Bulletin. The Fourth Implementing Ordinance was adopted on 30 July 1998.

According to the Atomic Energy Act, a license is required for the construction, operation or any other holding of a stationary installation for the production, treatment, processing or fission of nuclear fuel or reprocessing irradiated fuel (but no further license for commercial nuclear power plants will be granted). A license is also required for essentially modifying such an installation or its operation and for decommissioning. The applicant can only be granted a license if they meet the individual requirements spelled out by the Atomic Energy Act that includes as license prerequisites:

- trustworthiness and qualification of the responsible personnel;
- necessary knowledge of the otherwise engaged personnel regarding safe operation of the installation;
- necessary precautions against damage in the light of the state of the art in science and technology;
- necessary financial security with respect to legal liability for paying damage compensation;
- protection against disruptive actions or other interference by third parties; and
- consideration of public interests with respect to environmental impact.

The Radiation Protection Ordinance, adopted on 13 October 1976 (repealed and replaced by the 2001 Radiation Protection Ordinance) regulates in a legally binding way the reporting by name of the responsible persons for the radiation protection of the licensee, the dose limits of radiation exposure during operating conditions for the personnel engaged at the plant and for the general public. Furthermore, it contains planning values for doses from potential exposure in case of design based accidents of nuclear power plants.
Concerning the safety of nuclear power plants, the Federal Environmental Ministry (BMU) has the federal competence, whereas the execution of federal laws lies within the responsibility of the federal states, the Länder. So the licensing of nuclear installations is carried out by the Länder, where different ministries are responsible for licensing of construction, operation, essential modification and decommissioning of nuclear power plants. For technical matters in the licensing procedure and the supervision of nuclear facilities, the regulatory authorities of the Länder are supported by independent technical support organizations, in general the nuclear departments of the Technical Inspection Agencies (TÜV).

The actual details and procedure of licensing are specified in the Ordinance concerning the procedure for licensing nuclear installations, adopted on 18 February 1977, which repealed and replaced the 1960 Nuclear Installation Ordinance and was last amended in 2001. It deals specifically with the application procedure, with the submission of supporting documents and with the participation of the general public. It deals, furthermore, with the assessment of any environmental impact and with the consideration of other licensing requirements (e.g. regarding the possible release or discharge of non-radioactive pollutants into air or water).

To preserve the legal uniformity for the entire territory of the Federal Republic of Germany, the BMU supervises the licensing and supervisory activities of the Länder authorities (so-called "federal executive administration"). Supervision by BMU includes the right to issue binding directives.

2.1 Main national laws and regulations on nuclear power and waste management

- Atomic Energy Act (Atomgesetz), as amended in 2002.

- Precautionary Radiation Protection Act (Strahlenschutzvorsorgegesetz) and its Forth Implementing Ordinance.
- Radiation Protection Ordinance (Strahlenschutzverordnung)
- Licensing Procedure Ordinance (Atomrechtliche Verfahrensverordnung)
- Financial Security Ordinance (Atomrechtliche Deckungsvorsorge-Verordnung) , repealed and replaced by the 1977 Ordinance, adopted on 18 February and last amended in 2002.
- 1982 Ordinance on Advance Financial Contributions towards construction of Federal Installations for Safe Containment and Disposal of Radioactive Waste, the 1986 Extension of the Ordinance and its last amendment in 2004.
- 1977 Safety Criteria for Nuclear Power Plants.
- 1995 General Mining Ordinance: applying to underground radioactive waste repositories.

3 Policy objectives of Decommissioning

3.1 Introduction

As far as concerns the decommissioning of nuclear facilities, Germany has attained a unique position within Western Europe. It operates a system of statutory regulation, which explicitly addresses the issues and procedures for the decommissioning phase of a nuclear programme.

3.2 Practical Experience

In Germany, there is at present 20 nuclear reactors in operation. There has however been relatively little practical experience in the decommissioning of such facilities. This has been mainly due to the fact that the estimated operating lifetimes of the facilities is 40 years and the larger reactors were only initially put into operation in the early 1970's. However, decommissioning experience has been generated as a result of the decommissioning of two smaller reactors; one at Niederaichbach and the other at Gundremingen[2].

3.3 Legal Aspects

The initial legislative enactment dealing with the operation of nuclear facilities did not envisage the resultant decommissioning problem. Indeed, the Atomic Energy Act (AEA) of 1959 dealt primarily with licensing and operational safety aspects.[3] However, by virtue of the

4th Amendment to the AEA in 1976, the German legislature adopted provisions to deal with decommissioning license requirements and procedures[4]. Section 7(3) of the AEA states that "*Decommissioning a facility....and the safe containment of a permanently decommissioned facility or dismantling of a facility or parts of a facility shall require licenses.*"
There has been considerable discussion as to the legal effect of the wording of this provision. It has centred around the issue of whether or not dismantling should or should not follow the process of self containment. Giving the provision a literal translation, it seems unlikely that the German legislature intended the provision to be read as a statutory decommissioning sequence. Clearly, the provision offers alternatives under which decommissioning licenses can be issued.

3.4 Licenses

Licenses under Section 7(3) of the AEA may only be granted if the prerequisite conditions are fulfilled. The conditions are transplanted from those which relate to the construction and operation of nuclear facilities in Germany[5]. Separate licences are required for withdrawal from service, safe enclosure and dismantling[6].
There is considerable discretion enjoyed by the Licensing Authority, with no legal right of the granting of a decommissioning license. This is probably the reason why no financial provision pertaining to decommissioning funds is included within the scope of the AEA. It seems apparent that if the License Authority has a degree of discretion and may impose supplementary conditions on decommissioning applicants, then it can quite easily, by virtue of this discretion, ensure that any decommissioning application is adequately funded.
Since 1977, prospective plant operators must take the issue of decommissioning into account in the initial design phase of the facility. Criterion 2.10 of the Safety Criteria for Nuclear Power Plants stipulates that a concept for dismantling the facility must be presented during the initial application for a construction and operating license[7]. Such requirements are however not statutory in nature. By virtue of section 19(3) of the AEA.
"*Supervision of the nuclear facility's operations shall continue until the radiation from all facility structures and components fall below permitted levels.*"
Until this point, the competent authority may issue orders and directions relating to any aspect of the facility's operations, including decommissioning.

4 Compliance with international guidelines and regulations

As a member state of the European Union (EU), the OECD Nuclear Energy Agency (NEA), and the International Atomic Energy Agency (IAEA), Germany supports various international programmes in nuclear safety and nuclear waste management. In direct international co-operation Germany also supports projects and organisations, for example the licensing and supervisory authorities, technical support organisations and also research institutes.

5 Decommissioning of nuclear reactors – current situation

The following tables identify the various reactors and their state of decommissioning.

5.1 1. Nuclear power plants and prototype reactors

Table 1 : NPPs (Power and Prototype reactors) - in decommissioning

No.	Name	Abbrev.	Reactor type	Power MW_e	First criticality	In routine operation since	Shut-down date	decommissioning started	Operator (Decomm.)	Location of site
1	Rheinsberg (p.a.)	KKR	PWR / WWER	70	1966-03-11	1966	1990-06-01	1995-04-28	Energiewerke Nord GmbH (EWN)	Rheinsberg (BB)
2	Kompakte natriumgekühlte Kernanlage (p.a.)	KNK II	SNR	21	1977-10-10	1979	1991-08-23	1993-08-26	Forschungszentrum Karlsruhe GmbH	Eggenstein-Leopoldshafen (BW)
3	Mehrzweck-forschungsreaktor (p.a.)	MZFR	PWR / D_2O	57	1965-09-29	1966	1984-05-03	1987-11-17	Forschungszentrum Karlsruhe GmbH	Eggenstein-Leopoldshafen (BW)
4	Obrigheim	KWO	PWR	357	1968-09-22	1969	2005-05-11	2008-08-28	EnBW Kernkraft GmbH (EnKK)	Obrigheim (BW)
5	Gundremmingen-A	KRB-A	BWR	250	1966-08-14	1967	1977-01-13	1983-05-26	Kernkraftwerk Gundremmingen GmbH	Gundremmingen (BY)
6	Versuchsatomkraft-werk Kahl	VAK	BWR	16	1960-11-13	1962	1985-11-25	1988-05-05	VAK	Kahl (BY)
7	Greifswald-1 (p.a.) Unit 6 has never reached criticality, but is also part of the plant (twin blocks)	KGR 1	PWR / WWER	440	1973-12-03	1974	1990-12-18	1995-06-30	Energiewerke Nord GmbH (EWN)	Lubmin (MV)
8	Greifswald-2 (p.a.)	KGR 2	PWR / WWER	440	1974-12-02	1975	1990-02-14	1995-06-30	Energiewerke Nord GmbH (EWN)	Lubmin (MV)
9	Greifswald-3 (p.a.)	KGR 3	PWR / WWER	440	1977-10-06	1978	1990-02-28	1995-06-30	Energiewerke Nord GmbH (EWN)	Lubmin (MV)
10	Greifswald-4 (p.a.)	KGR 4	PWR / WWER	440	1979-07-22	1979	1990-06-02	1995-06-30	Energiewerke Nord GmbH (EWN)	Lubmin (MV)
11	Greifswald-5 (p.a.)	KGR 5	PWR / WWER	440	1989-03-26	-	1989-11-30	1995-06-30	Energiewerke Nord GmbH (EWN)	Lubmin (MV)
12	Lingen	KWL	BWR	268	1968-01-31	1968	1977-01-05	1985-11-21 | 1988-03-30 (SE)	Kernkraftwerk Lingen GmbH (subsidiary of RWE Power AG)	Lingen (NI)
13	Stade	KKS	PWR	672	1972-01-08	1972	2003-11-14	2005-09-07	E.ON Kernkraft GmbH	Stade (NI)
14	Arbeitsgemeinschaft Versuchsreaktor Jülich (p.a.)	AVR	HTR	15	1966-08-26	1969	1988-12-31	1994-03-09	AVR GmbH (subsidiary of EWN GmbH)	Jülich (NRW)
15	Thoriumhoch-temperaturreaktor (p.a.)	THTR-300	HTR	308	1983-09-13	1987	1988-09-29	1993-10-22 | 1997-10-01 (SE)	HKG	Hamm-Uentrop (NRW)
16	Würgassen	KWW	BWR	670	1971-10-22	1975	1994-08-26	1997-04-14	E.ON Kernkraft GmbH	Würgassen (NRW)
17	Mülheim-Kärlich	KMK	PWR	1302	1986-03-01	1987	1988-09-09	2004-07-16	RWE Power AG	Mühlheim-Kärlich (RP)

(p.a.) finance by public authorities

Table 2 : NPPs (power and prototype reactors) completely dismantled or released from regulatory control

No.	Name	Abbrev.	Reactor type	Power MW_e	first criticality	in routine operation since	Shut-down date	decommissioning started | finalised	Operator (Decomm.)	Location of site
1	Heissdampfreaktor Grosswelzheim (p.a.)	HDR	HDR (Hot steam reactor)	25	1969-10-14	1970	1971-04-20	1983-02-16 | 1998-10-15 completely dismantled	Forschungszentrum Karlsruhe GmbH	Großwelzheim (BY)
2	Niederaichbach (p.a.)	KKN	DRR / D_2O-modera-ted	106	1972-12-17	1973	1974-07-31	1975-10-21 | 1995-08-17 completely dismantled	Forschungszentrum Karlsruhe GmbH	Niederaichbach (BY)

Table 3 : Research reactors being shutdown without decommissioning licence

No.	Name	Abbrev.	Reactor type; Power	First criticality	Date of shut-down	Application for decommissioning	Operator	Location of site
1	Forschungsreaktor München	FRM	Pool-type / MTR; 4 MW_{th}	1957-10-31	2000-07-28	1998-12-14	Technische Universität München	Garching (BY)
2	DIDO	FRJ-2	Tank-type / D_2O ; 23 MW_{th}	1962-11-14	2006-05-02	2007-04-27	Forschungszentrum Jülich GmbH	Jülich (NRW)
3	Forschungsreaktor Geesthacht-2	FRG-2	Pool-type / MTR; 15 MW_{th}	1963-03-16	1993-01-28 Application for shut down 1995-01-17 Licence for shut down and partial dismantling	Remark: FRG-2 is shut down and partially dismantled. Formal decommissioning is not possible, as the pool is in common use with FRG-1.	GKSS Forschungszentrum Geesthacht GmbH	Geesthacht (SH)

Table 4 : Research reactors – in decommissioning

No.	Name	Abbrev.	Reactor type; Power	First criticality	Date of shut-down	Decommissioning started	Operator	Location of site
1	SUR Berlin	SUR-B	homogenious (S) / SUR-100 ; 1,0E-07 MW_{th}	1963-07-26	2007-10-15	2008-12-01 (DeL)	Technische Universität Berlin, Institut für Energietechnik, Fachgebiet Kerntechnik	Berlin (BE)
2	Forschungsreaktor-2	FR-2	Tank-type / D_2O; 44 MW_{th}	1961-03-07	1981-12-21	1986-07-03 (DeL) | 1996-11-20 (SE)	Forschungszentrum Karlsruhe GmbH	Eggenstein-Leopoldshafen (BW)
3	Forschungsreaktor Neuherberg	FRN	Pool-type / TRIGA MARK-III; 1 MW_{th}	1972-08-23	1982-12-16	1983-05-30 (DeL) | 1984-05-24 (SE)	Helmholtz Zentrum München – Deutsches Forschungszentrum für Gesunheit und Umwelt (GmbH)	Oberschleißheim (BY)
4	Forschungs- und Messreaktor Braunschweig	FMRB	Pool-type / MTR; 1 MW_{th}	1967-10-03	1995-12-19	2001-03-02 (DeL) | 2005-07-28 (released from regulatory control except interim storage)	Physikalisch-Technische Bundesanstalt	Braunschweig (NI)
5	Rossendorfer Forschungsreaktor	RFR	Tank-type / WWR-SM; 10 MW_{th}	1957-12-16	1991-06-27	1998-01-30 (DeL)	Verein für Kernforschungs-technik und Analytik	Rossendorf (SN)

DeL Decommissioning licence
DiL Dismantling licence
SE Facility in safe enclosure

Table 5: Research reactors completely dismantled or released from regulatory control

No.	Name	Abbrev.	Reactor type; Power	First criticality	Shut-down date	Decommissioning started | finalised	Operator	Location of site
1	Schnelle Nullenergie-Anordnung	SNEAK	homogenious (S); 1,0E-03 MW$_{th}$	1966-12-15	1985-11-01	1986-06-03 (DeL) | 1987-05-06	Forschungszentrum Karlsruhe GmbH	Eggenstein-Leopoldshafen (BW)
2	Schnelle Unterkritische Anordnung	SUAK	Fast sub-critical assembly; 0 MW$_{th}$	1964-11-20 start of operation	1978-12-07		Forschungszentrum Karlsruhe GmbH	Eggenstein-Leopoldshafen (BW)
3	Schnell-Thermischer Argonautreaktor	STARK	Argonaut modified Argonaut-reactor; 1,0E-05 MW$_{th}$	1963-01-11	March 1976	1976 (DeL) | 1977	Forschungszentrum Karlsruhe GmbH	Eggenstein-Leopoldshafen (BW)
4	SUR Karlsruhe	SUR-KA	homogenious (S) / SUR-100; 1,0E-07 MW$_{th}$	1966-03-07	September 1996	1996-11-25 (DeL) | 1998-06-26	Forschungszentrum Karlsruhe GmbH	Eggenstein-Leopoldshafen (BW)
5	TRIGA Heidelberg I	TRIGA HD I	Pool-type / TRIGA MARK-I; 0,25 MW$_{th}$	1966-08-26	1977-03-31	1980-06-30 (DeL) 1980-12-11 (SE) 2006-01-16 (DiL) | 2006-12-13	Deutsches Krebsforschungs-zentrum	Heidelberg (BW)
6	TRIGA Heidelberg II	TRIGA HD II	Pool-type / TRIGA MARK-I; 0,25 MWth	1978-02-28	1999-11-30	2004-09-13 (DeL) | 2006-12-13	Deutsches Krebsforschungs-zentrum	Heidelberg (BW)
7	AEG-Nullenergiereaktor, Thermisch-Kritische Anordnung	TKA	Tank-type-type / thermisch critical assembly 1,0E-04 MW$_{th}$	1967-06-23	1973	1981-09-28 (DeL) | 1981-12-21	Kraftwerk Union AG	Karlstein (BY)
8	AEG-Prüfreaktor	PR-10	Argonaut; 1,8E-04 MW$_{th}$	1961-01-27	1976	1976-07-27 (DeL) | 1978-02-22	Kraftwerk Union AG	Karlstein (BY)
9	Siemens Argonaut Reaktor	SAR	Argonaut; 1,0E-03 MW$_{th}$	1959-06-23	1968-10-31	1992-08-28 (DiL) | 1998-03-20	Technische Universität München	Garching (BY)
10	Siemens Unterkritische Anordnung (SUA was part of SUR-München)	SUA	Sub-critical assembly; 0 MW$_{th}$	1959-06-01 Start of operation	1968	1968-10-31 (DeL) | 1992-08-28 (DiL) | 1998-03-20	Technische Universität München	Garching (BY)
11	SUR München	SUR-M	homogenious (S) / SUR-100; 1,0E-07 MW$_{th}$	1962-02-28	1981-08-10	1992-08-28 (DiL) | 1998-03-20	Technische Universität München	Garching (BY)
12	Berliner Experimentier-Reaktor	BER I	homogenious (L) / L-54(L); 0,05 MW$_{th}$	1958-07-24	Summer 1972	1974-02-15 (revocation of the operation licence) | 1974-04-23	Helmholtz Zentrum Berlin für Materialien und Energie	Berlin (BE)
13	SUR Bremen	SUR-HB	homogenious (S) / SUR-100; 1,0E-07 MW$_{th}$	1967-10-10	1993-06-17	1997-06-05 (DeL) 1999-07-27 (DiL) | March 2000	Hochschule Bremen	Bremen (HB)
14	SUR Hamburg	SUR-HH	homogenious (S) / SUR-100 1,0E-07 MW$_{th}$	1965-01-15	August 1992	1999-03-31 (DeL) | December 1999	Fachhochschule Hamburg	Hamburg (HH)
15	Forschungsreaktor Frankfurt-1	FRF 1	homogenious (L) / L-54(L); 0,05 MW$_{th}$	1958-01-10	1968-03-19	1970 (DiL) | 2006-10-30	Johann-Wolfgang-Goethe-Universität	Frankfurt (HE)
16	Forschungsreaktor Frankfurt-2 (Reactor building contains residues of FRF-1, a GA L-54-type liquid reactor)	FRF-2	Pool-type / modified TRIGA; 1 MWth	no criticality	no operation	1982-10-25 (DiL) | 2004-12-28 (DeL) | 2006-10-30	Johann-Wolfgang-Goethe-Universität	Frankfurt (HE)
17	SUR Darmstadt	SUR-DA	homogenious (S) / SUR-100; 1,0E-07 MW$_{th}$	1963-09-23	1985-02-22	1989-11-23 (DeL) | 1990-08-02 (DiL) | 1996-11-29	Technische Hochschule Darmstadt	Darmstadt (HE)
18	TRIGA-Hannover	FRH/TRIGA MHH	Pool-type / TRIGA Mark-I; 0,25 MW$_{th}$	1973-01-31	1996-12-18	2006-05-08 (DeL) | 13.03.2008	Medizinische Hochschule Hannover	Hannover (NI)
19	Forschungsreaktor MERLIN	FRJ-1	Pool-type / MTR; 10 MW$_{th}$	1962-02-23	1985-03-22	1995-06-08 (DeL) | 2007-11-23	Forschungszentrum Jülich GmbH	Jülich (NRW)
20	Abbrandmessung differentieller Brennelemente mit kritischer Anordnung	ADIBKA	homogenious (L) / L77A; 1,0E-04 MW$_{th}$	1967-03-18	1972-10-30	1977-07-07 (DeL) | December 1977	Forschungszentrum Jülich GmbH	Jülich (NRW)
21	Kritische Anordnung für Hochtemperaturreaktoren	KATHER	critical assembly; 1,0E-04 MW$_{th}$	1973-07-02	1984-02-03	1987-11-09 (DeL) | June 1988	Forschungszentrum Jülich GmbH	Jülich (NRW)
22	Kritisches Experiment zum Incore-Thermionik-Reaktor	KEITER	critical assembly; 1,0E-06 MW$_{th}$	1971-06-15	1982	1982-03-18 (DeL) | June 1988	Forschungszentrum Jülich GmbH	Jülich (NRW)
23	Rossendorfer Anordnung für kritische Experimente	RAKE	Tank-type-type / critical assembly; 1,0E-05 MW$_{th}$	1969-10-03	1991-11-26	1997-08-19 (DeL) | 1998-10-28	Verein für Kernforschungs-technik und Analytik	Rossendorf (SN)
24	Rossendorfer Ringzonenreaktor	RRR	Argonaut; 1,0E-03 MW$_{th}$	1962-12-16	1991-07-01	1999-03-31 (DeL) | 2000-05-11	Verein für Kernforschungs-technik und Analytik	Rossendorf (SN)
25	Zittauer Lehr- und Forschungsreaktor	ZLFR	Tank-type / WWR-M; 1,0E-05 MW$_{th}$	1979-05-25	2005-03-24 last operation	2005-07-01 (DeL) | 2006-05-03	Hochschule Zittau/Görlitz (FH) FB Maschinenbauwesen	Zittau (SN)
26	Anlage für Nulleistungsexperimente	ANEX	critical assembly; 1,0E-04 MWth	1964-05-01	1975-02-05	1979-03-19 (DiL) | January 1980	GKSS Forschungszentrum Geesthacht GmbH	Geesthacht (SH)
27	Nuclear cargo vessel "Otto Hahn" Competent authority was in Hamburg (port of registry)	OH	PWR / Propulsion reactor; 38 MWth	1968-08-26	1979-03-22	1980-12-01 (DeL) | 1982-09-01	GKSS Forschungszentrum Geesthacht GmbH	Geesthacht (SH)
28	SUR Kiel	SUR-KI	homogenious (S) / SUR-100; 1,0E-07 MWth	1966-03-29	1997-12-11	2008-03-19 (DeL) | 2008-04-02	Fachhochschule Kiel	Kiel (SH)

DeL Decommissioning licence
DiL Dismantling licence

Worldwide there have been six Material Test Reactors of the DIDO Class[8]:

- HIFAR (High Flux Australian Reactor), Australia, Shut-Down: 30. January 2007
- Forschungsreaktor Jülich 2 (FRJ-2) am Forschungszentrum Jülich, Shut-Down: 2. Mai 2006
- DR-3 im Risoe-Forschungszentrum, Danmark, Shut-Down: 26. November 1999
- PLUTO, Atomic Energy Research Establishment (AERE), Great Britain, Shut-Down: 1990
- DIDO, Atomic Energy Research Establishment (AERE), Great Britain, Shut-Down: 1990
- DMTR (Dounreay Materials Test Reactor), Dounreay Nuclear Power Development Establishment, Great Britain, Shut-Down: 1969

The FRJ-2 is a reactor of the DIDO type and is thus moderated and cooled by heavy water (D_2O) contained in a closed tank. It was put into operation by Forschungszentrum Jülich GmbH in November 1962 with a power of 10 MW. The power was first increased to 15 MW in 1967 by exhausting available reserves and then to 23 MW in 1972 after appropriate modification and upgrading. Thirty horizontal tubes penetrate through the concrete shielding and the graphite reflector. Eight of these beam tubes and one through tube lead into the maximum or near maximum thermal neutron flux of 2 x 10^{14} cm^2s-1. These tubes are almost exclusively used for neutron scattering experiments as far as spatial conditions permit. In addition, there are more than thirty vertical tubes, some of them containing facilities used for special (fuel and structural material) and standard (isotope production and neutron activation analysis) irradiations.

The reactor is in shut-down conditions with graphite reflector still in place. The definite grade of the graphite is not known. It is either ARS or AMC or AMT from Siemens Plania. All activation data is based on calculations. Sampling of the graphite is in preparation.
Figure 2 shows the Cross section through the FRJ-2 reflector assembly with an indication of related temperatures and neutron fluxes.

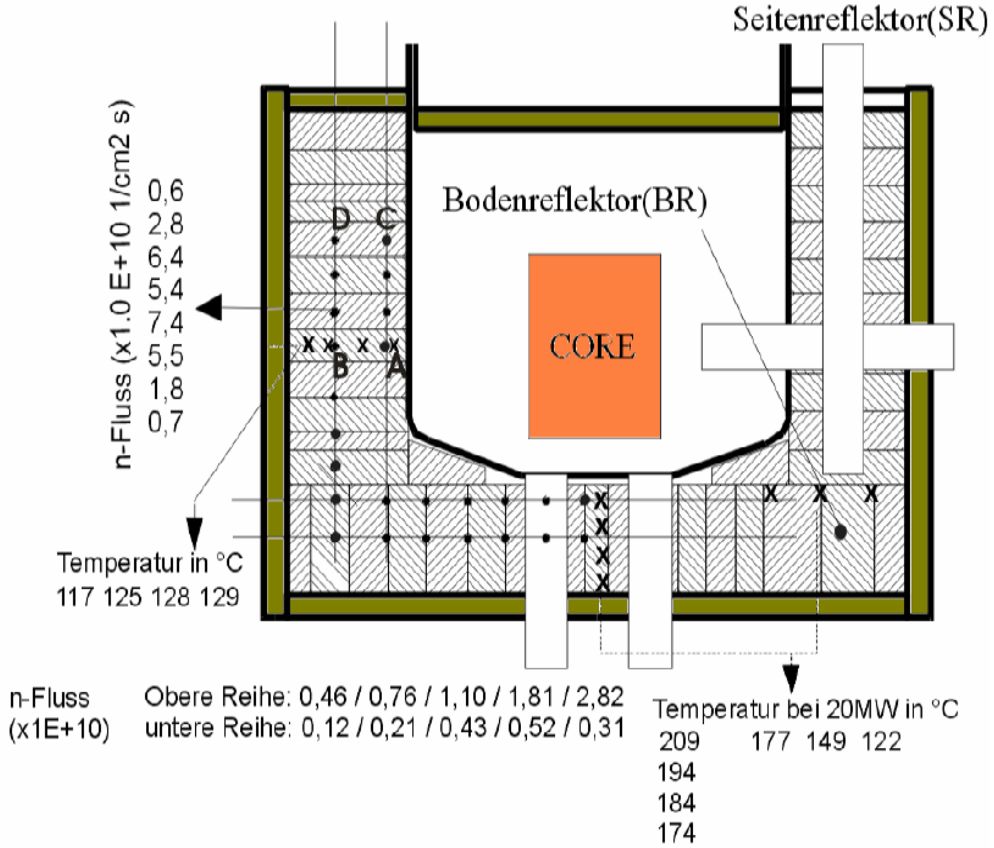

Figure 2 : Cross Section of FRJ-2

6 Graphite characteristics

The information reported in table 6 is specific for the DIDO material test reactor at Juelich. In addition to graphite characteristics for both virgin and irradiated reactor environmental conditions are also identified.

Table 6 : Material test reactor FRJ-2 Germany

Reactor Type	**MTR (DIDO – FRJ-2)**	
Number of reactors to be decommissioned	1 in Germany	
Total quantity of Graphite	30 Mg	
Quantity of graphite in reflector	26 Mg	
Quantity of Graphite in Thermal Column	4 Mg	
Years of operation	1962 -2006	
Operational Temperatures (Coolant)	54 - 64°C	
Temperature of Reflector	65 – 210°C (Gamma Heating)	
Type of Coolant / Atmosphere	D_2O	
Atmosphere of Reflector	Helium	
Atmosphere of Thermal Column	Air	
Graphite characteristics/properties	Un-irradiated	irradiated
Origin/supplier	Siemens Plania, Griesheim, Germany	XXXXXXXXXXXX
Grade	ARS/AMC/AMT ?	xxxxxxxxxxxxxx
Type		xxxxxxxxxxxxxx
Neutron dose	xxxxxxxxxxxx	
Density	1,6 – 1,7	
Impurities and concentration (ppm)	1800	
Gas permeability		
Open pore volume	24-28%	
Closed pore volume		
Hardness		
Radioactivity to include ^{14}C, ^{36}Cl and ^{60}Co levels	XXXXXXX	8.2E10 Bq (after 15 a)
- C14		7.5E10
- Co60		7.2E+9

7 Graphite retrieval objectives

According to current German regulations the contaminated/activated graphite from dismantling will have to be treated as low- or intermediate –level waste with negligible heat production.

At present, cutting of large-sized material and packaging with or without immobilisation in containers suitable for final disposal represents the basic management mode for irradiated graphite. Alternative methods aiming at the reduction of radionuclide content (e.g. tritium for operating and carbon-14 for long term safety) are presently being investigated. However, the irradiated graphite management option most appropriate under plant as well as site specific aspects, taking into account economical, ecological and safety criteria, has not yet been identified.

8 References

[1] www.nea.fr/html/general/profiles/germany.html

[2] Niederaichbach was a 100 MWe pressure tube reactor which was decommissioned after only 18 days of operation. It only achieved a 40% yield of its rated power and was retracted from service due to being technically inadequate in the face of advancing technology. Gundremingen was a 250 MWe reactor which was partially decommissioned in the late 1970's. Once again, technical inadequacy forced the Gundremingen reactor out of service and full decommissioning will commence at the start of the new century.

[3] Act on the Peaceful Utilisation and the Protection Against its Hazards (AEA) 1959,as amended, December 21 1992, BGBI I p.814.

[4] BGBI I p.2573

[5] *Supra* note 76, at sec. 7(2) No.1-No.6. They require the applicant to ensure the reliability and responsibility of the appropriate personnel; the necessary knowledge of the personnel in relation to safe operation, safety measures and possible hazards; the necessary precautions in the light of state of the art to prevent damage arising from decommissioning; financial security to cover all legal liability; necessary protection from interference from 3rd parties; and compatibility with public interests and in particular to protect the environment

[6] European Commission Report - A review of the situation of decommissioning of nuclear installations in Europe, EUR 17622 EN, European Communities 1997.

[7] Safety Criteria for Nuclear Power Plants, October 1977, Bundesanzeiger, No.206. Other relevant enactments include, the Model Rules for the Use of the State Collecting Facilities for the Radioactive Wastes in the FRG (1981) and the Decommissioning Guide (Draft, February 1995).

[8] Wikipedia