Research Reactors in Germany: An Overview

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Abstract. In Germany, experience was gained in the field of research reactors during the last five decades. In this paper, an overview about the legislative and regulatory framework in Germany is given particularly with respect to research reactors, as well as a survey of the plant and licensing status of the facilities in Germany. In total, 46 research reactors were built and operated. At present, 12 research reactors are in operation. The actual decommissioning and dismantling projects comprise 10 research reactors. Furthermore, 24 facilities have been dismantled completely and the sites are released from regulatory control.

1. Introduction

The history of civil use of nuclear energy in Germany began in 1955 after the Federal Republic of Germany became a sovereign state and officially renounced the development and possession of nuclear weapons. The legislation, administrative authorities and jurisdiction created for the peaceful use of nuclear energy establish the framework of the system for assuring the protection of life, health and property of the directly employed and the general public from the hazards of nuclear energy and the damaging effects of ionising radiation. On this basis, more than 30 prototype reactors and nuclear power plants were operated, and also several facilities of the nuclear fuel cycle. Besides the activities for the commercial use of nuclear energy, a considerable number of nuclear research centers and universities were equipped with 46 research reactors facilities altogether.

After the federal election in 1998, Germany decided the structured phase-out of nuclear power instead of its promotion. According to the respective amendment of the Atomic Energy Act in 2002, this corresponds specifically to the end of use of nuclear energy for the commercial generation of electricity in nuclear power plants, but does not refer to research reactors.

2. Participants in the Nuclear Licensing and Supervision Procedures

The Republic of Germany is a federal state. According to the Basic Law "(Grundgesetz"), the Federal Government has the legislative competence for the peaceful use of nuclear energy. However, the Atomic Energy Act is mainly executed by the Federal States ("Länder") on behalf of the Federal Government, represented by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

Fig. 1 shows the participants and their interactions in the nuclear licensing and supervision procedures. This overall picture is exactly the same for both nuclear power plants and research reactors. The licensing procedure and the continuous regulatory supervision of the facilities lie within the responsibility of the individual "Länder". The competent authorities may involve authorised experts in technical or scientific questions, but they are not bound by the respective assessments. In a licensing procedure, other "Land" and subordinate authorities whose jurisdiction is involved shall take part.

These are, in particular, authorities responsible under the building code, the water code, for regional planning and for off-site disaster control. The licensing authority also involves the general public.

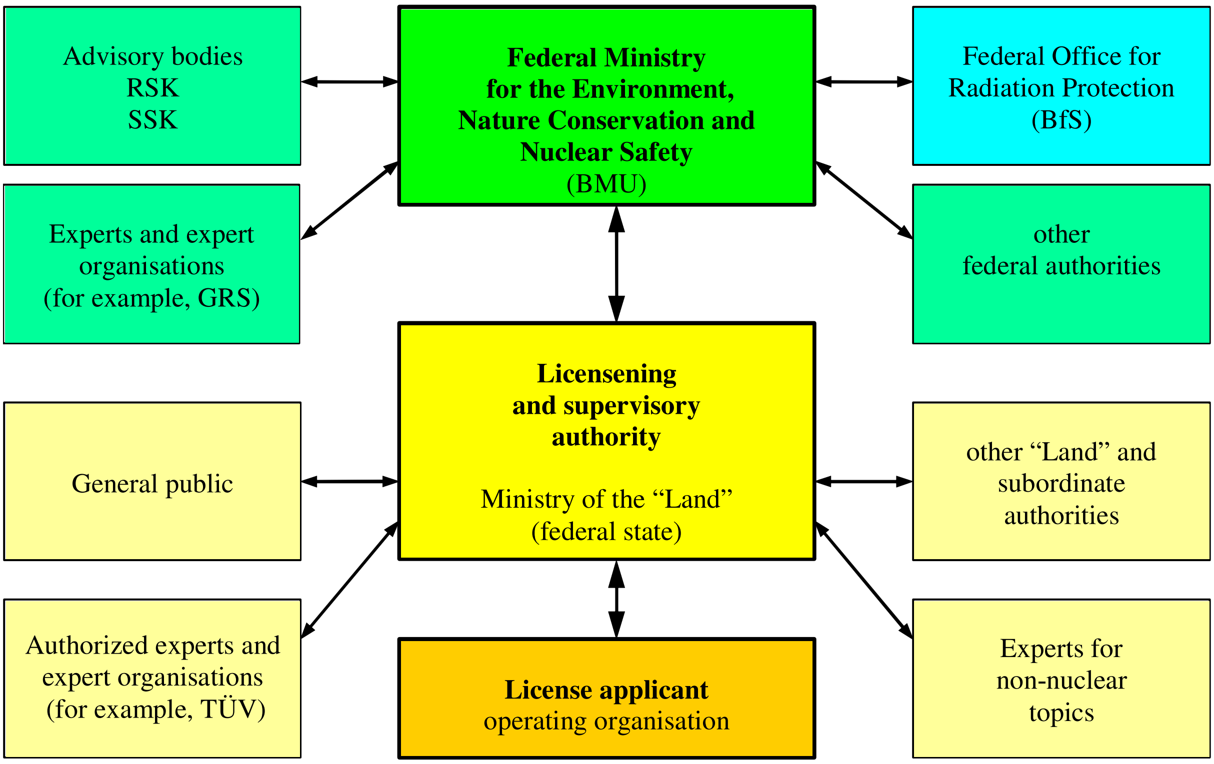

FIG. 1. Participants in the Nuclear Licensing and Supervision Procedure

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 regarding lawfulness and expediency. This also includes the right to issue binding directives on factual and legal issues in each individual case. In performing its execution of federal supervision, the BMU is supported by the Federal Office for Radiation Protection (BfS) as a subordinate authority. The BMU also receives advisory support from the Reactor Safety Commission (RSK) and the Commission on Radiological Protection (SSK) [see 3.5]. Furthermore, it consults external experts, in particular the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS).

3. Nuclear Safety Regulations

In Germany, the various nuclear safety regulations may be seen as structured hierarchically in the form of a pyramid (Fig. 2). At the top of the pyramid, the Atomic Energy Act [see 3.1] and its associated ordinances [see 3.2] constitute the legal basis and are directly binding to all kind of nuclear installations in a common approach.

Below the legal level, the general and abstract safety provisions and regulations of the Atomic Energy Act and the associated ordinances are put into concrete terms by various sublegal nuclear safety regulations [see 3.3 – 3.6] and by conventional technical standards [see 3.7]. In principle, these sublegal nuclear regulations are not mandatory, but in fact can be made binding by specification in the license or by supervisory measures in the individual case. Moreover, most of the sublegal nuclear safety regulations were mainly developed for nuclear power plants. However, in the regulatory practice, they are applied by analogy or with some interpretation for research reactors, in accordance with the potential hazards of the specific research reactor by means of a graded approach.

The most essential nuclear safety regulations are presented hereafter with special respect to research reactors. They are documented in the Handbook on Nuclear Safety and Radiation Protection at the BfS website www.bfs.de [1] and may be downloaded. To a considerable extent, they are available also in English translations.

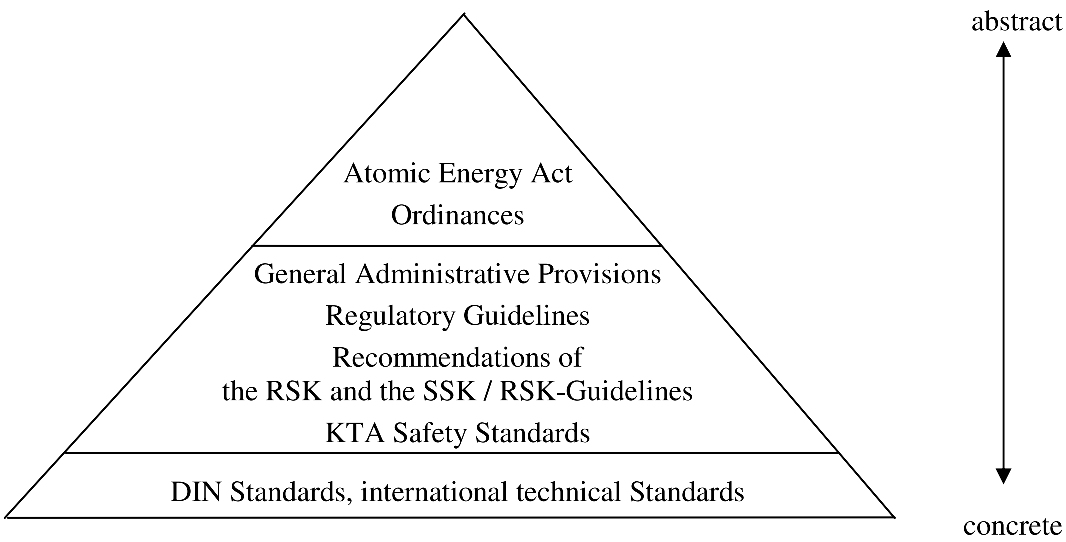

FIG. 2. Hierarchical Overview of Nuclear Safety Regulations

3.1. Atomic Energy Act

The Atomic Energy Act [1] was first promulgated December 23, 1959. Since then, it has been updated and amended several times. A significant amendment occurred in 2002, based on the agreement between the Federal Government and the four most important power utilities of 14 June 2000 (signed on 11 June 2001). Its new purpose is to phase-out the use of nuclear energy for the commercial generation of electricity in an orderly manner. Therefore, no further licenses will be issued for the construction and operation of installations for the fission of nuclear fuel for the commercial generation of electricity anymore. Furthermore, the utilisation of the existing nuclear power plants is limited by restricting the residual electricity output that may be produced, with the basic assumption of an overall operating lifetime of 32 years. In fact, the phase out is in force for nuclear power plants for commercial generation of electricity, but not for research reactors.

According to Section 7(1) of the Atomic Energy Act, a license is required for the construction, operation or any other holding of a stationary installation for the fission of nuclear fuel, or for essentially modifying such installation or its operation. This applies to research reactors. A license may only be granted if the license prerequisites according to Section 7(2) are fulfilled by the applicant:

- trustworthiness and technical qualification of the responsible personnel,
- necessary knowledge of the otherwise engaged personnel regarding safe operation of the installation,
- necessary precautions against damage according to the state of the art in science and technology,
- necessary financial security with respect to legal liability for paying damage compensation,
- protection against malevolent acts or other illegal interference by third parties, and
- consideration of public interests with respect to environmental impacts.

Furthermore, nuclear installations are subject to continuous regulatory supervision during their entire lifetime, from the start of construction to the end of decommissioning.

3.2. Ordinances

On the basis of the Atomic Energy Act, a number of ordinances have been promulgated in the field of nuclear energy. As well as the Atomic Energy Act, these ordinances are mandatory for all kind of nuclear installations, and the most essential are discussed below.

3.2.1. Radiation Protection Ordinance

The Radiation Protection Ordinance [1] includes provisions by which human beings and the environment are protected from damage due to natural and man-induced ionising radiation. Within this ordinance, requirements and limits are laid down to be observed when using radioactive material. This also covers the handling of nuclear fuel, as well as construction, operation and decommissioning of nuclear installations in accordance with Section 7 of the Atomic Energy Act. Apart from construction, research reactors and nuclear power plants are treated in the same manner.

A central aspect of the Radiation Protection Ordinance is the regulation of the radiation exposure of the general public during operating conditions of nuclear installations. A limit of 1 mSv per calendar year is specified for the effective dose to individuals by direct radiation, including the radiation exposure from discharges. The technical design and operation of a plant or installation has to be planned in such a way that the radiation exposure caused by discharge of radioactive material with air or water from these installations will not exceed the effective dose limit of 0.3 mSv per calendar year. Further limits are applicable to specified organs and tissues. The radiation exposure must be calculated for a reference person at the most unfavourable receiving point in the vicinity of the facility. Unfavourable nutritional habits and durations of stay are postulated for the reference person to ensure that the radiation exposure will be by no means being underestimated. The details to be considered are given in a respective general administrative provision [see 3.3].

Other important issues of the Radiation Protection Ordinance are the dose limits for occupational exposed persons. The prescribed limit for the effective dose is 20 mSv per calendar year, and the sum added in all calendar years must not exceed the life time dose of 400 mSv.

One more central issue is the radiation exposure of the general public during design basis accidents. In accordance with Section 49 it has to be shown in the licensing procedure for a nuclear installation – notwithstanding the obligation to minimise radiation exposure – that the effective dose in the vicinity will not exceed the planning value of 50 mSv in a design basis accident, integrated over all exposure paths as 50-year dose commitment. The analytical models and assumptions to be applied for these verifications are specified in the respective "Incident Guidelines" [see 3.4]. It has to be mentioned that Section 49 of the Radiation Protection Ordinance refers specifically to nuclear power plants, near site interim storage facilities for spent fuel assemblies and repositories for radioactive waste. For other nuclear installations, e.g. research reactors, the competent authorities specify in accordance with Section 50 the kind and scope of the protective measures taking into account the individual case, especially the hazard potential of the installation and the probability of the occurrence of a design basis accident.

3.2.2. Nuclear Licensing Procedure Ordinance

The Nuclear Licensing Procedure Ordinance [1] specifies the details and procedure of licensing of nuclear facilities. It deals specifically with the application procedure, with the submittal of supporting documents, with the participation of the general public and with the possibility to split the procedure into several licensing steps (partial licenses). Furthermore, it comprises the assessment of environmental impacts and the consideration of other licensing requirements, e.g. regarding the possible release or discharge of non-radioactive pollutants into air or water.

3.2.3. Nuclear Safety Officer and Reporting Ordinance

The Nuclear Safety Officer and Reporting Ordinance [1] contains the obligation of the licensees of nuclear installations to report accidents, incidents or other events relevant to safety (reportable events) to the competent supervisory authority. The nuclear installations concerned are nuclear power plants, all facilities of the fuel cycle and research reactors with a thermal power output larger than 50 kW as well. Each reportable event is assigned to one of the individual reporting categories: S (immediate report, without delay), E (quick report, within 24 hours), N (normal report, within 5 days) and V (before initial loading, within 10 days). In addition, the reportable events are also categorized according to the seven levels of the INES scale of the IAEA.

Special reporting forms were developed for recording and categorising reportable events in accordance with approximately 80 reporting criteria. These reporting criteria are subdivided into radiation criteria which are the same for all nuclear installations and individual criteria applicable to plants for the fission of nuclear fuel or to installations of the nuclear fuel cycle respectively. The reporting criteria for plants for the fission of nuclear fuel refer mainly to light water reactors, and therefore shall apply to research reactors by analogy. To support this procedure, special explanations for the application of these criteria for research reactors were worked out [1]. These explanations are not contained in the ordinance itself, but have been established well in practice.

Currently, the Reporting Ordinance is in revision, and one of the main aspects is to provide individual reporting criteria also for research reactors. It is expected that the revised ordinance will be in force in 2008.

On behalf of the BMU, the BfS performs the central collection and documentation of all reportable events in Germany. Since 1991, when the Ordinance came into force, 228 reportable events occurred in the 16 German research reactors with a thermal power larger than 50 kW. All of them have been Category N for events with a low significance to safety and level zero on the INES scale.

3.3. General Administrative Provisions

The general administrative provisions are at a level just below the acts and ordinances. They present general binding regulations for the actions of the regulatory bodies. With respect to research reactors, especially the "General Administrative Provision for the Calculation of Radiation Exposure of the General Public during Operating Conditions of Nuclear Facilities" [1] has to be mentioned. In accordance with the Radiation Protection Ordinance, this provision contains the analytical models and parameters for the respective calculations [see 3.2.1].

3.4. Regulatory Guidelines

Regulatory guidelines describe the view of the BMU on general questions related to nuclear safety and the administrative practice. In contrast to the general administrative provisions, the guidelines are not mandatory for the "Länder" authorities. Nevertheless, in general they are discussed and adjusted by consensus in a permanent "Federation-Länder" Committee for Nuclear Energy and serve as an orientation regarding the execution of the Atomic Energy Act. The most important regulatory guidelines are the "Safety Criteria" [1], which include the general safety requirements for a nuclear power plant, and the "Incident Guidelines" [1], which describe in accordance with the Radiation Protection Ordinance the details on the design basis accidents to be considered especially in the design of a pressurised water reactor [see 3.2.1]. These two guidelines, as well as most of the other guidelines which exist in the field of nuclear technology, were developed for nuclear power plants. For research reactors, they are applied as far as practicable. There are two regulatory guidelines implemented specifically for research reactors, and both are relating to the technical qualification of research reactor personnel:

- Guideline Relating to the Proof of the Technical Qualification of Research Reactor Personnel [1],
- Guideline Relating to the Content of the Examination of Technical Qualification of the Responsible Shift Personnel in Research Reactors [1].

The two guidelines apply to the determination of the technical qualification of the personnel of research reactors with a thermal power of more than 300 kW. Its application to TRIGA, experimental and training reactors with a lower thermal power will depend on the decision of the competent licensing or supervisory authority in the particular case.

3.5. Recommendations of the RSK and the SSK, RSK-Guidelines

The Reactor Safety Commission (RSK) and the Commission on Radiological Protection (SSK) are expert commissions with appointed members. They advise the BMU in questions of fundamental importance related to nuclear safety and radiation protection. The results of the deliberations of the two commissions are formulated as general recommendations and as statements on individual cases, which are published at their respective websites www.rskonline.de [2] and www.ssk.de [3]. As a basis for its recommendations, the RSK uses the last version of the “RSK-Guidelines” of 1996, which summarises the safety requirements to be fulfilled regarding the design, construction and operation of a nuclear power plant with pressurised water reactor.

As well as the basic RSK-Guidelines, most of the recommendations concern nuclear power plants. However, they are also applied in analogy or with some interpretation for research reactors. Moreover, some recommendations from the RSK and the SSK regarding specific licensing procedures of individual research reactor facilities have been made. As examples, a recommendation concerning the licensing procedure for upgrading of the thermal power of the BER II (Forschungsreaktor Berlin II) from 5 to 10 MW in 1985 [1] as well as three recommendations regarding licensing issues for the new research reactor FRM-II in 1996 [1], 1997 [1] and 2001 [2] may be mentioned [see 4.1].

3.6. KTA Safety Standards

Detailed and concrete technical requirements are contained in the safety standards of the Nuclear Safety Standards Commission (KTA). In accordance with its statutes, the KTA specifies requirements wherever "experience leads to a uniform opinion of the experts within the groups of manufacturers, construction companies, and licensees of nuclear installations, and of the expert organisations and the authorities." On the basis of the regular reviews and eventual amendment of the issued safety standards at intervals of no more than five years, the standards are adjusted to the state of the art in science and technology. They are also published at the KTA-website www.kta-gs.de [4]. In themselves, KTA safety standards are not legally binding. However, due to the nature of their origin and their high degree of detail, they have a far-reaching practical effect.

As well as the other sublegal nuclear regulations, most of the KTA Safety Standards are mainly developed for nuclear power plants with light water reactor. In practice, they are also applied to research reactors, but their special physical characteristics are taken into account. There is only one KTA Safety Standard issued specifically to research reactors, namely KTA 1507 “Monitoring and Assessing of the Discharges of Radioactive Substances from Research Reactors” [4].

3.7. Conventional Technical Standards

Naturally, conventional technical standards are also applied in the design and operation of all kind of technical installations, just as they are, as far as these standards correspond to the state of the art in science and technology. In particular, the national standards of the German Institute for Standardisation (DIN) and also the international standards of ISO and IEC are taken into account.

3.8. International Framework

In Germany, the legislation and its execution must also take into account any binding requirement from regulations of the European Union. With respect to radiation protection there are, among others, the EURATOM Basic Safety Standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation.

The nuclear safety regulations concerning nuclear installations are in compliance with the international accepted safety standards, e.g. the "Safety Fundamentals" of the IAEA. Currently, the development of new sublegal nuclear safety regulations to replace the "Safety Criteria" and the "RSK-Guidelines" as well as to integrate current international regulations is in progress.

In 2004, the IAEA Board of Governors approved the "Code of Conduct on the Safety of Research Reactors". To comply with its recommendations, the German Federal Government included research reactors in the report for the third review meeting in April 2005 [5] for the "Convention on Nuclear Safety". The report for the fourth review meeting in 2008 is currently in preparation.

4. Research Reactor Facilities in Germany

In Germany, experience has been accumulated in the field of research reactors during the last five decades. In October 1957, the "Forschungsreaktor München" (FRM) reached criticality as the first nuclear facility in Germany. Since then, in total 46 research reactors were built and operated. In the meanwhile, most of them are in decommissioning or have already been dismantled completely. Concerning the design, there is, or has been, a very broad range of different types of research reactors. The variety of facilities includes large pool or tank reactors with a thermal power of several tens of megawatt as well as small educational reactors with a thermal power in the order of only hundred milliwatts and critical assemblies. A complete compilation of all research reactors in Germany is presented at the BfS web site www.bfs.de, Nuclear Safety, Nuclear Facilities in Germany [6].

4.1. Research Reactors in Operation

At present, 12 research reactors are still in operation in Germany. Four of these research reactors have a thermal power of more than 50 kW and – particularly with regard to the obligations of the Reporting Ordinance [see 3.3.2] – may be seen as "larger" facilities.

- FRG-1: pool type MTR, 5 MW, enrichment 20 %, first criticality 1958
- FRMZ: pool type TRIGA, 100 kW, enrichment 20 %, first criticality 1965
- BER II: pool type MTR, 10 MW, enrichment 20 %, first criticality 1973
- FRM-II: pool type compact core, 20 MW, enrichment 93 %, first criticality 2004

The remaining 8 research reactors in operation are small educational reactors with a thermal power not exceeding 2 Watts. It has to be mentioned, that most of them are foreseen for decommissioning in the near future.

The newest – and maybe internationally the best known – German research reactor is the high flux neutron source FRM-II (Fig. 3, centre). It became critical for the first time in March 2004 and started routine operation in April 2005. Hereafter, a brief description about the plant characteristics of the facility [7] and the licensing procedure is presented.

FIG. 3. FRM-II (centre) and FRM (right hand side) [7]

The FRM-II is a high performance research reactor to deliver neutrons for fundamental research and industrial and medical applications as well. A maximum undisturbed thermal neutron flux of 8 x 10^{14}/(cm^{2}·sec) is achieved at a relatively low nominal thermal power of 20 MW. The concept is based on the use of a compact core containing a single cylindrical fuel element installed in the centre of a moderator tank filled with heavy water. Cooling is performed with light water from the reactor pool. The reactor is controlled by means of the central control rod inside the fuel element. To shut it down, an additional, independent system of five shutdown rods is provided in the moderator tank. Each system is individually capable of shutting the reactor down quickly and permanently anytime. The outer walls of the reactor building consist of 1.8 m of reinforced concrete and are designed to withstand the impact of an earthquake or even the impact of a high speed military aircraft, as required particularly in the respective RSK-Guidelines for pressurised water reactors.

The compact core consists of a single, cylindrical fuel element. Its inner diameter is 118 mm, its outer diameter 243 mm and its active height is approx. 700 mm. The fuel element with its packaging is approx. 1.3 m high and contains a total of 8.5 kg of highly enriched uranium in an uraniumsilicide-alumium dispersion fuel. It is made up of 113 involuted, curved fuel plates. In order to homogenise the power and fission density, the uranium content in the outer zone of each fuel plate is reduced from 3 g/cm^3 to 1.5 g/cm^3. The average power density amounts to more than 1000 kW/liter. With a cycle length of 52 days, 5 fuel elements will be required per year [7].

The history of the FRM-II started with the conceptual design phase around 1980. The goal was to replace the existing FRM, the so-called “Atomic Egg” (right hand side Fig. 3), which was the first research reactor in Germany and is now in decommissioning. In 1993, the application for the construction and the operation of the FRM-II was submitted to the competent licensing “Länder” authority of Bavaria. In Accordance to Section 18(1) of the Nuclear Licensing Procedure Ordinance [see 3.2.2] the licensing procedure was split into several licensing steps. The licensing authority granted three partial licenses according to Section 7(1) of the Atomic Act, particularly based on the respective evaluation reports by their authorised experts.

- April 4, 1996: first partial license for the suitability of the site, the basic construction features and the construction of the reactor building as well as a preliminary positive general assessment
- October 10, 1997: second partial license for the construction of the additional buildings and the mechanical and electrical installations

- May 2, 2003: third partial license for the introduction of the fuel element and the nuclear operation

In Accordance with the Nuclear Licensing Procedure Ordinance [see 3.2.2], the Bavarian licensing authority involved the general public in the licensing procedure for the first partial license, above all for the direct protection of the citizens who might be affected by the plant installation. Therefore, a public announcement of the project and a public disclosure of the application documents, especially the safety report, were made. In May 1995 a public hearing has been carried out where the objections were discussed between the licensing authority, the applicant and the persons who had raised the objections.

Within the frame of federal executive administration, the Bavarian licensing authority also had to include the BMU in the licensing procedures. The BMU stated its position to each partial licensing procedure, essentially based on the basis of the respective recommendations of his advisory bodies RSK and SSK in 1996 [1], 1997 [1] and 2001 [2]. Within the licensing procedure for the final operating license the BMU issued a directive binding to the licensing authority. A central point of this directive was to impose an obligation in the license to reduce the fuel of the reactor from highly enriched uranium to uranium with an enrichment of not more than 50 % U 235 until the end of the year 2010. To comply with this obligation, the operator TUM (Technische Universität München) has established an international working group to develop a new high density fuel on the basis of a uranium-molybdenum alloy. However, due to various unresolved problems in the required international research and development activities, it has to be noticed that this goal obviously will not be reached.

4.2. Research Reactors in Decommissioning

The Atomic Energy Act and its associated ordinances provide the legal basis for the construction and operation of nuclear facilities as well as their decommissioning. Nevertheless, the sublegal nuclear safety regulations were primarily created for the construction and operation of these facilities. In view of the large number of decommissioning projects, the BMU – together with the regulatory bodies of the Länder – prepared in 1996 a "Guide to the Decommissioning of Facilities as Defined in Section 7 of the Atomic Energy Act" [1]. This "Decommissioning Guide" includes proposals for an appropriate procedure for the decommissioning of nuclear facilities with respect to the application of the sublegal nuclear safety regulations. The proposals are primarily aimed at the decommissioning of nuclear power plants and therefore need to be considered specifically for research reactors. The "Decommissioning Guide" is well established in practice, also for research reactors, and is currently in revision.

According to Section 7(3) of the Atomic Energy Act, the decommissioning of a nuclear facility, as well as the safe enclosure of an installation or the dismantling of an installation or of parts thereof requires a license. As in the case of licenses for the construction and operation of nuclear facilities, the licenses for decommissioning may be split into several licensing steps.

In the decommissioning of nuclear facilities in Germany two approaches are established:

- Immediate dismantling: This option involves the dismantling of a nuclear facility immediately after its final shut-down. The dismantling of a large research reactor may take about ten years or more, whereas the dismantling of a small educational reactor can be realized in a few months including the licensing procedure.
- Safe enclosure: This option involves removing radioactive material from a nuclear facility after its final shut-down and then transforming it into an almost maintenance-free condition. It remains in this state for a certain period of time (e. g. 30 and up to 100 years or more) and is then dismantled.

Legally, both options have equal ranking. Each of the two options has its advantages and disadvantages, and the decision is taken by the licensee on a case by case basis. However, in most decommissioning projects for research reactors – as well as for nuclear power plants – the direct dismantling is favoured.

Actually, there are 10 research reactors in decommissioning. All of them have a thermal power of more than 50 kW and therefore – with respect to the obligations of the Reporting Ordinance [see 3.3.2] – may be regarded as "larger" facilities. Two of these facilities are in a safe enclosure, and 8 facilities are in dismantling. Hereafter, a brief overview is given for the FRJ-1 (MERLIN) as a typical example for the decommissioning process of a "larger" research reactor in Germany.

The FRJ-1 is a light water moderated and cooled pool reactor of British design with a thermal power of 10 MW. After an operation time of 23 years the facility was shut down in 1985 due to economic reasons. The fuel elements were removed from the facility within the framework of the operating license and were transferred for reprocessing to the USA and GB. Originally, a safe enclosure of the reactor block was foreseen, but the decision was changed to a direct dismantling. In 1995, a license was issued particularly concerning the dismantling of the air cooler. In 1997, the first partial decommissioning license was issued, including also the dismantling of parts of the facility. On this basis and further partial licenses issued in 2000, 2001 and 2004 the dismantling of the facility was done stepwise – essentially coolant loops, reactor tank internals and reactor block – and has now been nearly finished. Currently, the decontamination of the reactor hall is in progress and the measurements for the release of the buildings from nuclear regulatory control are in preparation.

Additionally to the 10 decommissioning projects in progress, already 24 research reactor facilities have been dismantled completely and the sites are released from regulatory control. Most of them are small educational reactors or critical assemblies. A supervision under nuclear legislation is not necessary any more and the sites may be used for other purposes without any restrictions.

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