DECOMMISSIONING OF GERMANY'S FIRST NUCLEAR REACTOR

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ABSTRACT

FRM started operating in 1957 as the first research reactor in Germany. Reactor operation ended in 2000. Licensing procedures for the deconstruction and dismantling of the reactor started shortly afterwards. In 2014 the Technical University of Munich (TUM) was granted the license to decommission the reactor.

In our contribution we describe our (long) way to the license for dismantling of the reactor and give a short overview of the current state of the decommissioning project.

We present the results of the (pre-)licensing stage: disposal of spent nuclear fuel (SNF), fire protection, radiological characterization (neutron activation and contamination), waste management, safety analysis.

With regard to the current state of the project we will discuss: clearance of material and current obstacles.

1. Introduction[1]

1.1 Construction, licensing and commissioning

In the 1950s the Bavarian government gave impulses for the transformation of Bavaria from an agricultural to an industrial country. The worldwide euphoria towards the peaceful use of nuclear energy was shared by the leading political parties in Germany, left-wing as well as right-wing parties.

It took an incredibly short time – compared to today's time consuming licensing processes – from the political decision to build a nuclear research reactor near Munich to the first criticality of the research reactor in Munich (FRM):

In 1956 the Bavarian government decided to buy a research reactor. A few days after the political decision, Professor Maier-Leibnitz (Physics Department of the TUM) was sent to the USA with the task of buying a nuclear reactor.

When the reactor was bought from AMF, there was no federal legislation regarding nuclear installations. The construction of the FRM started in 1956, without the legislation that would be necessary for reactor operation. With the approval of the Bavarian government the construction of the FRM started - still without any federal nuclear law. In 1957 the Bavarian government passed a nuclear law of their own, before the federal government had an appropriate nuclear law for the Federal Republic of Germany. The Bavarian law was the basis for the license of Germany's first nuclear reactor.

In October 1957 first criticality was achieved, thus making the FRM the first nuclear installation in Germany.

1.2 Technical overview

The FRM was designed as neutron source for science and material test reactor.

It was a light-water-moderated open pool reactor (see Figure 1).

From 1957 to 1960 the fuel was 20% enriched uranium (U-Al-alloy). With a reactor power of 1 MW a maximal neutron flux of 6.6 * 10^{12} n/cm²/s was achieved.

In order to further increase neutron flux, the use of 90% enriched uranium (HEU) started in 1960.

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[1] The main contents of the introduction were collected from the articles in [1].

In 1962 a system to irradiate samples near liquid Helium temperature (TTB) was installed very close to the reactor core.
In 1966 the reactor power was increased to 2.5 MW and in 1968 to 4 MW.
In 1982 the core design was completely refurbished. The operating team added Beryllium and Graphite reflector elements and was able to increase the neutron flux to 8 * 10^{13} n/cm²/s.
In 1995 a cold neutron source was installed.

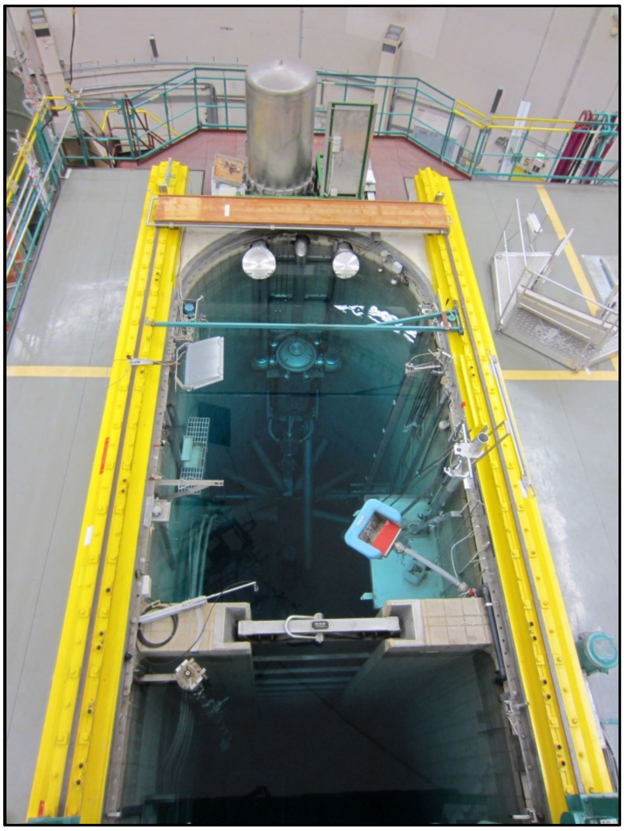

Figure 1: Reactor pool of the FRM

1.3 Scientific highlights

The FRM always was a reactor for scientific purposes and the scientific use of neutrons. Power generation was not of interest.
The main fields of science at FRM were: nuclear physics, neutron physics, solid-state physics, irradiation techniques and radiochemistry. Ultracold neutrons (UCN) were first detected at the FRM by A. Steyerl et al. [2].

Many techniques that are still used today at neutron source type research reactors were developed or greatly refined at FRM including:
spectroscopy, mass spectroscopy of fission products, interferometry, neutron guides, small angle scattering, fast pneumatic tube system and gravity refractometry.

1.4 End of operation

When it was decided to build a new high flux neutron source next to FRM, it was also decided to decommission the old reactor. Licensing for decommissioning started in 1998.
The last reactor operation took place in the year 2000. Since 2002 FRM has had no fuel elements on site.
The license for decommissioning was granted in 2014.

2. Licensing for decommissioning

2.1 General legislation

In order to decommission a nuclear installation in Germany the licensee of the running installation has to request a license for decommissioning.
The licensee's request has to contain a detailed safety report. The safety report has to cover the following items:

- geographic location
- neighbouring infrastructure (residential, industrial and agricultural areas)
- technical description of the nuclear installation
- description of the planned procedure for practical decommissioning
- radiation safety
- waste management
- fire protection
- possible incidents/accidents
- personnel organisation of the operator

After receiving the safety report, the licensing authority asks a technical safety organisation (TSO) for their expert opinion regarding the safety report and its contents. The TSO writes a final report commenting on each point of the safety report.

The licensing authority grants the license for decommissioning, if it is convinced that the decommissioning can be done safely for people and the environment.

2.2 Licensing at FRM

FRM requested a license for decommissioning in 1998. A new environmental impact assessment (Umweltverträglichkeitsprüfung UVP) with participation of the public was not required due to the fact that only already licensed values were requested for permissible emissions (1 E6 Bq aerosol-bound activity per year).

Shortly after the first request, all licensing efforts for decommissioning were put on halt, as all resources from FRM, authority and TSO were needed for the licensing and commissioning of the new high flux neutron source FRM II.

Finally, in 2010 FRM negotiated a contract with a nuclear consulting company, to get the licensing done. In this process the contractor prepared all the documents and discussed them with the operator, the TSO and the licensing authority - the Bavarian state ministry of the environment, health and consumer protection (StMUV).

The TSO and the licensing authority were involved during the whole process of preparing the safety report. Both already knew the FRM form the operating time in great detail, which facilitated the unavoidable technical discussions.

After the submission of the safety report by FRM, the TSO reviewed the report and wrote a detailed report themselves. The overall result was positive. Still, the TSO requested some conditions to be met before the start of dismantling.

The licensing authority granted the license in 2014 [3]. Basis of the license are:

- the safety report presented by FRM,
- the technical report presented by the TSO (conditions, written down by the TSO, did not necessarily become requirements of the licensing authority),
- federal and national legislation and
- additional national regulations.

The whole process from reactor operation to license for decommissioning is summed up in Table 1.

Table 1: FRM's way from reactor operation to decommissioning

Year	Activities towards license for decommissioning
1957-2000	Reactor operation of FRM under operating license
1998	Operator (FRM) requests license for decommissioning
1998-2010	FRM, TSO and authority are busy with licensing and commissioning of the new high flux research reactor FRM II
2010-2012	FRM working with a contractor to finalize the licensing documents
2010-2014	FRM, contractor, TSO and authority discuss details of the licensing documents and prepare additional documents
2014	License for decommissioning is granted by the authority

3. Description of the (pre-)licensing stage

This chapter describes the main challenges during the pre-licensing stage: the disposal of spent nuclear fuel and writing up the safety report. The parts of the safety report (see chapter 2.1), that are of general interest, are described in detail.

Figure 2 shows the "atomic egg" – with circumferential rooms - from the outside.

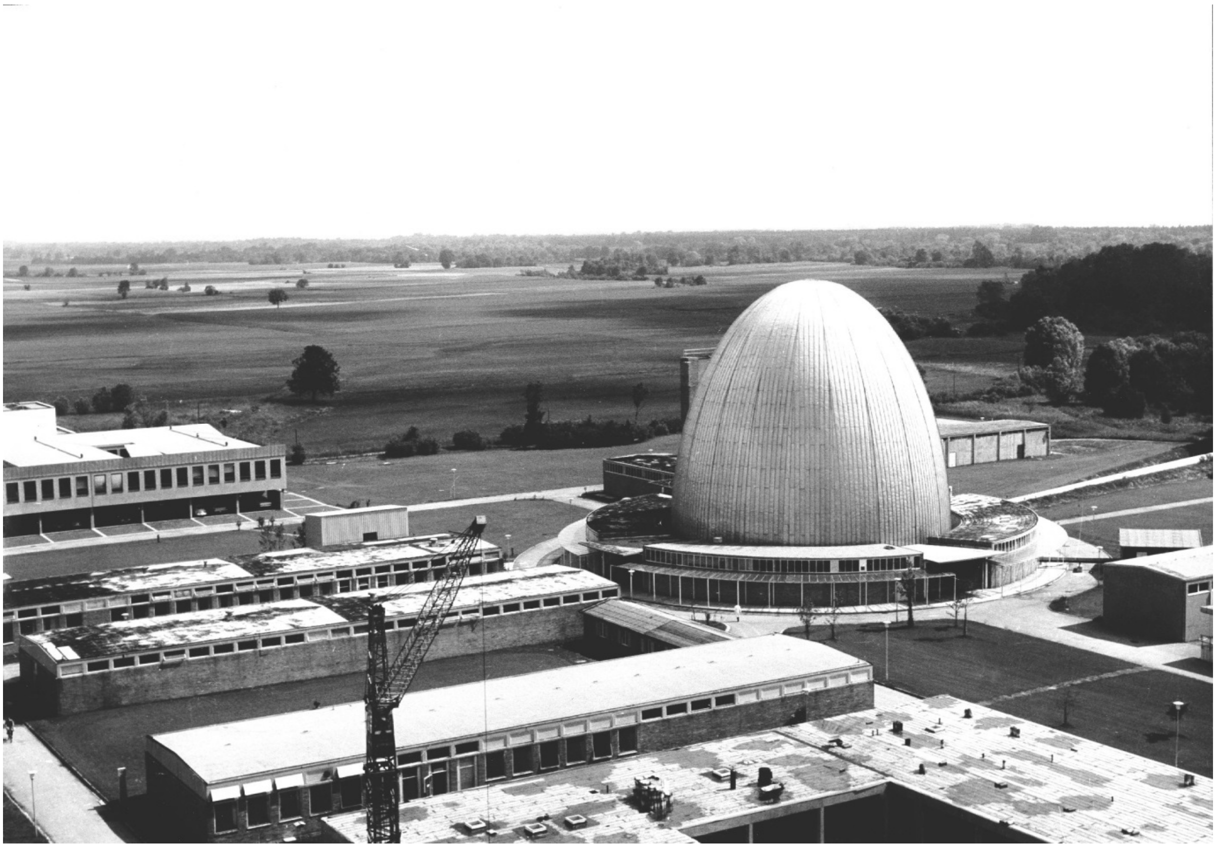

Figure 2: Historic picture of the FRM

The licensed area of the FRM consists of the reactor hall – containing the open pool (see Figure 1) - and additional rooms around the "atomic egg". The adjacent rooms contain storage rooms, a laboratory and rooms for systems such as ventilation and waste water treatment.

3.1 Disposal of spent nuclear fuel

The main part of the spent nuclear fuel from FRM was highly enriched uranium. Supporting the international effort of minimizing civilian HEU stockpiles, the FRM participated in the repatriation of the spent nuclear fuel back to the United States in 2002. The packaging of the SNF took place still under the operating license.
This step reduced the radioactive inventory at the FRM drastically.

3.2 Fire protection

Fire protection is gaining more and more focus in international and German regulations. This is especially the case after tragic accidents in industrial [4] and private building complexes.

The German Nuclear Safety Standards Commission (KTA) published regulations concerning fire protection in nuclear power plants (i.e. reactors commercially producing electricity) under the national regulation KTA 2101 in 1985. This regulation is being updated on a regular basis.

The fire protection at the research reactor FRM has always been inspired - but not governed - by this KTA rule. Especially because of the age and the structural design of the reactor hall it is not always possible to fully comply with KTA-rule 2101. There is consensus that because of the low risk arising from the decommissioning of the FRM this is tolerable.

The main outline of the fire protection concept is as follows:

- use of burnable substances and burnable structural materials is minimized at FRM – especially in controlled areas
- utilization units (e.g. ventilation system, reactor hall, emergency battery room) are separated by walls and doors with a fire-resistance rating that guarantees a resistance time of 90 minutes (following DIN 4102-5) at a conventional fire,
- every room is monitored by fire/smoke detectors,
- there are hand held fire extinguishers for firefighting by the FRM personnel (only small fires),
- the combination of fire-resistant structural material und detector systems gives the Werkfeuerwehr (fire department of the TUM located at the campus site [5]) enough time to arrive for firefighting,
- there are enough outdoor and indoor hydrants for the fire department to do their work.

All the installations necessary for fire protection and the inventory of burnable substances on the site are checked on a regular basis by the operator. Additionally there are yearly site inspections by the TSO, which include a detailed review of the operator’s inspection protocols.

3.3 Radiological characterisation

The reactor hall and most of the reactor systems were known to be very clean – with regard to radioactivity - throughout the decades of reactor operation. Still, there was one known contamination event with Eu-152/Eu-154 in the pneumatic rabbit system that contaminated the tube system, the reactor hall and the ventilation system.

In order to show that safe decommissioning is possible with respect to radioactive waste and safety of the working personnel, it was necessary to characterize the radiological situation at the FRM – after removal of SNF. The methodology and the main results of the radiological characterisation are described in the following.[2]

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[2] The results presented are mainly from work done by the contractor [6]

Gamma dose rate measurements:

Gamma dose rate measurements were executed for a first overview in the reactor hall, the pump room – containing the primary circuit, the heat exchanger and the water cleaning system - and on the reactor platform. The dose rate levels were very low at every place (< 5 µSv/h).

No new contamination was found. Only places with known contamination could be confirmed: pneumatic rabbit system, heat exchanger, waste storage areas and some experiments. The dose rate from activated core components is negligible as long as the open pool is filled with water.

Gamma spectrometry:

In order to determine the most important nuclides in-situ measurements with a gamma spectrometer were performed at spots of increased dose rate. The results are presented in Table 2

Table 2: Results from gamma spectroscopy

Measured spot	Relevant isotopes
Heat Exchanger	Co-60, Ag-108m, Cs-137, Eu-152, Eu-154
Pneumatic Tube System	Co-60, Ag-108m, Cs-137, Eu-152, Eu-154
Contaminated parts from the Reactor Pool	Co-60, Cs-137
Ventilation System	Co-60, Cs-137, Eu-152, Eu-154
Reactor Hall – concrete wall	Only naturally occurring nuclides

Contamination measurements:

To determine the contamination of the reactor hall and reactor systems, swipes were taken and measurements with hand held contamination monitoring devices were performed. The three main results were:

- there is no relevant contamination – with one exception: inside the pneumatic tube system
- Co-60 and Cs-137 are the main contaminants
- there are no relevant isotopes (excluding the pneumatic tube system), which are difficult to measure (e.g. H-3, Alpha emitters)

Neutron activation calculations:

Neutron activation calculations for the components close to the reactor core and close to the neutron beam tubes were performed to determine the remaining main radioactive inventory (see Table 3 to Table 5).

Table 3: Total activity of the wall of the reactor pool

Nuclide	Total activity in concrete [Bq]	Total activity in steel [Bq]
H-3	3.1 E07	--
C-14	2.0 E04	1.5 E04
Fe-55	4.3 E06	1.0 E09
Co-60	2.5 E06	1.3 E07
Ba-133	1.3 E08	--
Eu-152	3.9 E06	--
Eu-154	2.7 E05	--

Table 4: Total activity of the aluminum components close to the core

Nuclide	Total activity in concrete [Bq]
Mn-54	5.2 E07
Fe-55	1.1 E12
Co-60	5.4 E11
Ni-59	2.5 E09
Ni-63	3.3 E11
Zn-65	5.9 E12

Table 5: Total activity of the steel components close to the core

Nuclide	Total activity in concrete [Bq]
Mn-54	1.1 E07
Fe-55	3.5 E11
Co-60	7.7 E09
Ni-59	1.7 E09
Ni-63	2.2 E11

<u>Summary:</u>
The main part of the remaining radioactivity in the reactor hall is activation of the components close to the core. The handling of the highly activated components is not trivial (dose rates up to 1 Sv/h for components very close to the reactor) but possible. It is possible to comply with the acceptance criteria for final disposal.
There are only a few contaminated systems (pneumatic rabbit tubes, primary circuit with heat exchanger). The decommissioning of these systems will be technically possible.

3.4 Waste management

<u>Clearance/free release of material from controlled areas:</u>
Most of the material from the controlled areas of the FRM can be released without any restriction. For this clearance measurements have to be performed by FRM and those measurements have to be confirmed by an independent third party (at FRM: the Bavarian State Agency for the environment (LfU)). After that the material is cleared for unrestricted use or restricted conventional disposal.

<u>Conventional pollutants:</u>
Due to the age of the FRM there are several conventional pollutants that have to be taken into account when planning the disposal.
No asbestos could be found so far.

In order to shield some of the neutron beam guide tubes going through the reactor hall, concrete tubs containing water were built around the neutron guide tubes. The concrete shielding tubs were constructed from concrete bars that were joint by material containing PCB (sum PCB 9.2 g/kg). The concrete bars were covered with insulating material also containing PCB and lead (sum PCB 2 g/kg; Pb 11 g/kg).

There are two possible ways of disposing of the concrete contaminated with PCB for the FRM:

- breaking up the concrete into small parts (size of a human fist), burning every single piece, disposing of the pieces conventionally

- disposing of the concrete bars in appropriate containers at a licensed underground disposal site.

The disposal route preferred by the competent state disposal company is the underground disposal site.

Disposal of radioactive waste:
The activated components and some contaminated pieces have to be prepared for disposal in a federal final repository. At the moment FRM has to prepare the radioactive waste in such conditions (stable, packaging, limit for activity, limit for conventional pollutants) that it complies with the acceptance criteria of Schacht Konrad [7].

There are wastes at the FRM site that cannot be brought in such a form, that they comply with the acceptance criteria. The problematic wastes are:

- beryllium reflector elements and
- graphite reflector elements.

The disposal of the FRM reflector elements is an unresolved problem. The TUM Institute for Radiochemistry already presented information regarding the disposal of the beryllium elements [8].
For the licensed final repository Schacht Konrad the H-3-inventory (radioactivity) and the beryllium (conventional pollutant) inventory are too big. This is also the case for the C-14-inventory of the graphite elements. The responsible federal authority (former Federal Agency for Radiation Protection (BfS) now Federal Agency for Nuclear Disposal Safety (BfE)) is legally obliged to provide a final repository for this kind of wastes.

Until when the packaged wastes will be safely stored in a final repository, FRM remains the owner of the radioactive wastes, thus also responsible (also financially) to ensure safe storage of the radioactive material.

As stated above the spent nuclear fuel was already repatriated to the United States.

3.5 Safety analysis of possible accidents

The safety analysis of possible accidents and the possible resulting radiation dose to the public was done in accordance with German legislation and regulations.

For the safety analysis a conservative spectrum of possible incidents was select. They can be summed up as follows:

- long lasting fire in the reactor hall
- destruction of the reactor building with release of radioactivity (e.g. after an earthquake)
- outage of important systems

For the calculation of a possible release of radioactivity into the environment, the inventory of radioactivity at the FRM site was taken from the radiological characterisation described above (see chapter 3.3). The possible release of activity was calculated conservatively following national and international guidelines.

The German Radiation Protection Ordinance (Strahlenschutzverordnung - StrlSchV) requires that the effective radiation dose which follows the worst accident conditions has to be below 50 mSv. The result of the safety analysis was: the possible radiation dose for every group of age is well below the limits (also including radiation doses to the organs).

4. State of the project

4.1 Clearance of material

Clearance measurements are performed routinely by the FRM radiation protection personnel. The preferred method of such measurements is a circa 1 m³ box (FMA) with gamma-sensitive detectors on every side.

Clearance for unrestricted use of material that is measured in the FMA can be achieved within a few weeks – including the time the independent expert takes to verify the FRM measurements.
Material that can't be measured in the FMA - due to its size - can take a much longer time to achieve the clearance for unrestricted use (roughly half a year). Clearance measurements for this kind of material are performed with in-situ gamma spectrometry or hand-held contamination monitors with additional material probes.

Clearance for restricted use (i.e. conventional disposal) can take a much longer time (up to a few years). There are a few problems for this way of clearance:

- hard to find appropriate sites,
- hard to find sites willing to take material from a nuclear site,
- conventional authority and nuclear/radiation protection authority have to communicate
- operator has to coordinate everything.

4.2 Ventilation system

The license for decommissioning issued by the responsible authority described the present ventilation system as appropriate for the time of decommissioning.

The visualisation scheme of the present ventilation system is shown in Figure 3.

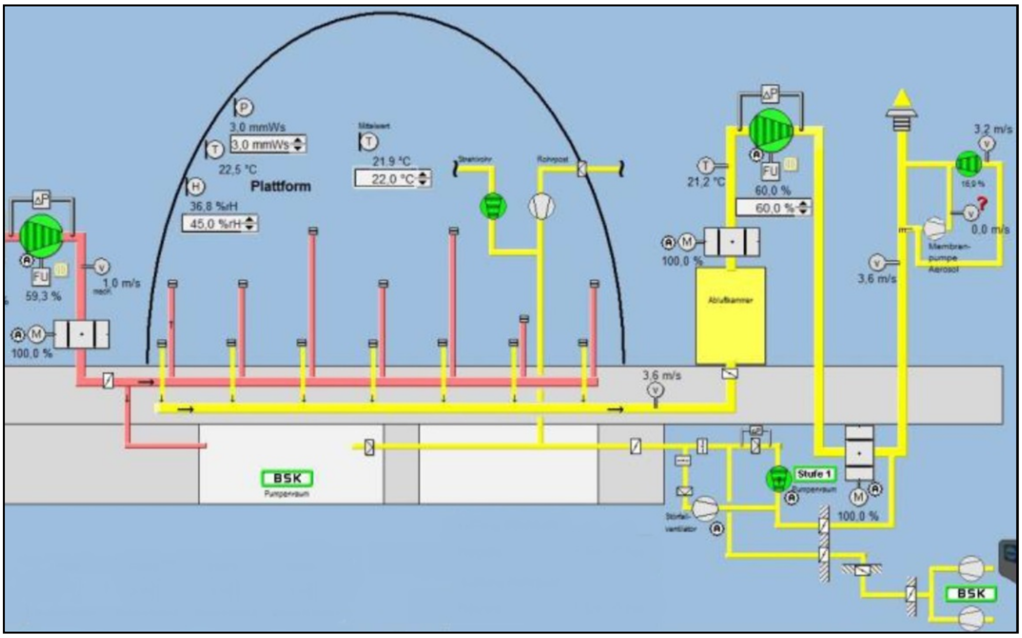

Figure 3: Visualisation of the unfiltered ventilations system

Because of the lack of filtration under normal operation (this was also the case during reactor operation) the TSO was able to come up with a scenario in which, because of the requested low permissible yearly emissions (1E6 Bq per year), the limit for one year could be exhausted into the air – undetected by the operator - in a few hours. Although the scenario described by the TSO seems to be extremely unlikely, FRM decided to install a new ventilation system for the time of decommissioning.

As long as the ventilation systems is not accepted by the licensing authority, FRM is not allowed to use tools in the reactor hall that could cause emission of aerosols into the air, thus rendering impossible every significant step in physical decommissioning.

4.3 Radioactive Waste

The radioactive material is still stored in the reactor hall. The components that were close to the reactor core are still in the reactor pool covered with water.
The disposal of radioactive waste is not going on at the moment. This is mainly due to the following:
The radioactive material can't be processed in the reactor hall because of the state of the ventilation system described in chapter 4.2. Additionally, appropriate financial rescources and personnel have not yet been allocated for the disposal of radioactive waste.

5. Conclusion

The history and current state of the FRM have been described. Once the remaining issues will be resolved, the decommissioning will proceed as licensed.

6. References

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7. Abbreviations

FMA	Freimessanlage (Release Measurement Facility)
HEU	Highly Enriched Uranium
KTA	Kerntechnischer Ausschuss (Nuclear Safety Standards Commission)
PCB	Polychlorinated biphenyl
SNF	Spent Nuclear Fuel
StMUV	Staatsministerium für Umwelt, Gesundheit und Verbraucherschutz (Bavarian state ministry of the environment, health and consumer protection)
TSO	Technical Safety Organisation