OPTIONS FOR THE MANAGEMENT OF FUEL FROM GERMAN TRAINING REACTORS

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1. Introduction

Training reactors have been operated at German universities and various research institutions for training purposes. These reactors are mostly Siemens training reactors of the SUR 100 type.

After decommissioning of the reactors, the fuel has to be disposed of or treated for reuse. Due to the low output of these reactors, fuel quantities to be managed are relatively small.

The options available for the management of this fuel are discussed hereinafter.

2. Reactor description

The Siemens training reactor SUR 100 ("**S**iemens-**U**nterrichts-**R**eaktor 100") is a thermal reactor with a solid, homogenous core enclosed by a graphite reflector and designed for a continuous output of 100 mW (in exceptional cases up to 1 W). The reactor's fuel elements are cylinder-shaped fuel-moderator plates with a diameter of approx. 240 mm and varying in thickness between approx. 5 mm and approx. 47 mm. U_3O_8 is used as fuel (enriched to 20%), embedded into high-pressure polyethylene used as moderator. The U_3O_8-polyethylene dispersion is a compacted homogenous powder mixture with approx. 0.06 g U-235/cm^3. A typical SUR contains about 10 fuel plates with a total uranium mass of approx. 3.5 kg (approx. 700 g U-235) and a total weight of approx.15 kg (U_3O_8 +PE).

The AKR training reactor (Ausbildungskernreaktor) of the Technical University of Dresden is a homogenous solid-moderated zero power reactor similar to the SUR-100 type. The maximum output of the reactor is 2 W. The fuel elements of the AKR are similar to those of the SUR, however the uranium is present as UO_2.

The ZLFR training reactor (**Z**ittauer **L**ehr- und **F**orschungs**r**eaktor) of the University of Zittau/Görlitz is a light water-moderated, unpressurized zero power reactor of the tank type, designed for an output of 10 W. The core is roughly cylinder-shaped, with a diameter of 350 mm, a height of 600 mm and it consists of 94 fuel elements of the WWR-M type. The fuel matrix of the fuel element tubes consists of a 36%-enriched U-235, rolled UO_2-Al dispersion.

3. Disposal needs

The current disposal needs for all 14 German training reactors is summed up below for the 12 SUR and the two other reactor types. In all the following quantities have to be handled:

	SUR	AKR / ZLFR	Total
Number of fuel elements	122	136	258
U-235 [kg]	8.464	4.757	13.221
U_{total} [kg]	42.582	15.533	58.115

4. Fuel element burnup

Owing to the low maximum output of the reactors – particularly in the case of the SUR-type reactors – the burnup of the fuel element is very low. Normally, these reactors were operated less than 50 hours per year on average, and a considerable percentage of this time was spent in start-up and shutdown operations for training purposes.

In order to assess the nuclide inventory of the fuel elements and to demonstrate that the fuel in terms of quality can be considered unirradiated fuel, a burnup calculation by means of the SCALE software system was performed for the SUR of the Technical University of Darmstadt which exhibits the highest burnup (energy produced approx. 3 kWh) of all the SUR reactors in question, as a calculation covering all SUR-type reactors.

As the calculations showed, the major share of the fuel element activity results from natural decay.

The calculated fuel activities are so low that the uranium fulfills the requirements of the definitions for "unirradiated uranium" as per IAEO regulations.

No specific burnup calculations were performed for the AKR and ZLFR because of the different disposal policy as compared to the SUR-type reactors.

5. Direct disposal of fuel

The pursuance of the direct disposal option at the present moment where no final repository is yet available implies preceding interim storage of the training reactor fuel. For the time being, the duration of the necessary interim storage period cannot be forecasted.

Assuming that all issues standing in the way of storage in this repository, the licensing procedure for which is under way, the theoretically earliest final disposal would be possible in the Konrad repository. From a merely technical point of view – leaving out of consideration any other influencing factors – this would be possible in four years from now (i.e. in 2004). In this case, interim storage for a period of at least three years would be necessary.

Disposal in a final repository at the Gorleben site can not be expected to be possible within the next ten years. An interim storage period of at least 10 years would thus ensue for this disposal option.

An analysis of the interim storage possibilities in Germany showed available and feasible storage capacities in the Ahaus fuel element interim storage facility, in the Jülich AVR cask storage facility and in the Rossendorf VKTA facility.

Interim storage preceding final disposal is possible only in licensed transport and storage casks, so that reloading of the SUR fuel from transport casks, which can be handled at the storage places, into transport and storage casks will be necessary.

At present, such possibility to reload the fuel plates into a transport and storage cask exists e.g. in the waste handling hot cell facility of the *Betriebsabteilung Dekontamination* of FZJ, provided that suitable adjustments are made to the reloading equipment; basically, reloading might also be done in another nuclear facility.

Storage possibilities at the possible sites are characterized below.

5.1 Interim storage

Interim storage in the Ahaus fuel element interim storage facility:

Interim storage of the SUR fuel plates in the Ahaus interim storage facility is possible in transport and storage casks of the CASTOR THTR/AVR or CASTOR MTR 2 types. Corresponding storage capacity is available.

Using the mentioned transport and storage casks for storage in Ahaus would offer the advantage that corresponding licenses / permits (transport and nuclear law) are already available which need to be amended only with regard to the radioactive inventory.

For interim storage of SUR fuel plates it is expedient that the transport and storage casks be charged with the SUR fuel plates in a nuclear facility equipped with handling systems for these cask types. This requires individual transports of the SUR plates from the storage place of the SUR plates to the facility where reloading into transport and storage casks is done.

Interim storage of the 122 fuel plates would require two casks of the CASTOR MTR 2 type or one cask of the CASTOR THTR/AVR type.

Interim storage in the AVR cask storage facility:

Interim storage of the SUR fuel plates in CASTOR THTR/AVR casks in the existing AVR cask storage facility is possible owing to the availability of storage capacity unused to date.

Such extension of the scope of use of the AVR cask storage facility would require an amendment to the existing license under § 6 AtG.

Carrying out fuel reloading in the waste handling hot cell facility of the Jülich *Betriebsabteilung Dekontamination* requires an amendment to or extension of the existing handling license under §9 AtG.

Storage in the VKTA Rossendorf:

For the fuel elements of the Dresden AKR and the Zittau ZLFR there is a disposal path in place, which provides for use of the VKTA Rossendorf facilities where the AKR and ZLFR fuel elements are envisioned to be kept available until shipment to a reprocessing plant. Disposal of these fuel elements through reprocessing is sought.

Storage of all SUR fuel plates until reprocessing is not considered by the operator and will not be further discussed within the scope of this investigation.

5.2 Final disposal

Final disposal in the planned Konrad repository

A review of the results of the calculations done for the reference plant (SUR of TU Darmstadt) against the activity limits of the storage conditions for the Konrad repository shows that – except for the activity limits and the mass limit for fissile materials resulting from the criticality analyses – the other activity limits for a complete SUR core are met for any of the permitted casks types.

According to the storage conditions for the Konrad underground repository, the maximum masses of fissile material storable in one waste package depends on the selected type of waste container. The numbers of packages required for storage of the entire SUR fuel resulting from the mass and activity limits for selected container types is given in the table below:

	Cask volume (gross) [m³]	Mass limit for fissile material per package [g]	Approximate number of packages required	Total storage volume [m³]
Concrete cask Type I	1.2	69	123	150
Cast steel cask Type I	0.7	50	170	119
Container Type I	3.9	170	50	195

The stated numbers of packages and storage volumes can be reduced by "mixed storage". That is to say that packages are loaded with more fuel if they are stored mixed with packages of lower activity inventory in one stacking row in the storage facility.

All in all, it can be said that final disposal of the fuel in the Konrad repository is afflicted with an unreasonably great storage volume, considering the relatively small volume of the fuel elements. The comparably most cost-efficient storage is possible if concrete casks type 1 are used in "mixed storage" mode.

As a further storage requisite, the basic storage condition of limiting the fissile material mass concentration to max. 50 g per 0.1 m^3 of waste form has to be complied with. Following conditioning of the fuel elements (dismantling of the fuel elements with subsequent immobilization) it is possible to meet this limit.

For storage the SUR has to be classified as radioactive waste. Furthermore, safeguards requirements have to be considered.

Final disposal in the planned Gorleben repository

The Gorleben salt dome has been studied since the end of the seventies for its suitability as a repository for all types of radioactive wastes, particularly for heat-emitting high-active wastes and irradiated fuel elements. At present, the first of the five exploration sections projected in the north-eastern part of the salt dome is being developed and subjected to geoscience studies.

Based on the exploration results, e.g. site-specific safety analyses are done to furnish proof of aptitude. The results of these analyses yet to be done (by 2005) will subsequently be translated into storage conditions and requirements. Consequently there are not yet any requirements and packaging regulations in place which will have to be met by radioactive wastes to be stored in the planned Gorleben repository.

6. Reuse of fissile material

As an alternative to final disposal of the low-irradiated fuel-moderator plates, the separation of the U_3O_8 from the polyethylene matrix of the plates and recycling of the extracted U_3O_8 in plants of the nuclear fuel cycles has to be considered.

The feasibility of separation of the U_3O_8 particles from the polyethylene matrix has to be demonstrated in preliminary studies before this disposal option is pursued. These studies, however, have not yet been completed.

Recycling of the recovered U_3O_8 is done in compliance with the acceptance conditions in nuclear fuel cycle facilities.

7. Direct disposal vs. reutilization

A comparison of possible disposal variants shows that at present the technical (except for interim storage) and licensing prerequisites are given for neither of the possible disposal options.

The separation of the fissile material from the polyethylene matrix seems to be feasible, but feasibility is yet to be demonstrated.

The implementation of final disposal in the Konrad repository can not be expected to occur before 2004. Estimates as to the timeline of final disposal in the planned Gorleben repository and of reprocessing (for the preliminary studies being not yet completed) are hardly possible at present.

A comparison of cost estimates for the different disposal options shows that the "mixed storage" variant in the Konrad repository is the most cost-efficient variant of the direct disposal option. Due to the lack of final disposal cost data, a cost estimate for storage in the Gorleben repository is not possible for the time being; however, it can be expected that due to the substantially smaller number of waste packages required (e.g. possibility of storage in CASTOR THTR/AVR casks without reloading into the final repository) cost will be significantly lower than those estimated for storage in the Konrad repository.

Based on the data available to date, the cost anticipated for the reprocessing option is higher than for the most cost-efficient final disposal variant. However, since the preliminary studies have not yet been done and/or completed, a new cost estimate and estimates as to the required implementation periods should be made upon demonstration of the feasibility of the separation of fissile material from the PE matrix, based on the validated data.

Based on the mentioned aspects it is recommendable to wait for the results of the preliminary studies on the separation of the SUR fuel from the PE matrix and the cost calculation based on them before a decision on the disposal option to be pursued is made, particularly since the results of the preliminary studies will be available even before the end of 1999. It is also hoped that by that date more information will be available about the future of the German repository projects.