Note:
This is a translation of the statement entitled "Anforderungen an bestrahlte Brennelemente aus entsorgungstechnischer Sicht".
In case of discrepancies between the English translation and the German original, the original shall prevail.

STATEMENT
Requirements for spent fuel from the point of view of waste management

Contents

1 Introduction and object of the statement

Against the background of the events in the Japanese nuclear power plants at the beginning of March 2011, the Federal Government is considering the immediate permanent cessation of operation of a number of nuclear power plants. As a part of the related measures, considerations have to be made concerning the management of spent fuel from these nuclear power plants. In particular, fuel elements are to be considered that have been inserted during the last refuelling outage in the respective nuclear power plant for the first time, as these have, compared to fuel elements with higher burn-up, a different content of uranium and plutonium isotopes.

2 Request of advice of the BMU

In connection with the permanent shutdown of some LWR plants, the Federal Environment Minister requested the ESK to prepare an ESK statement in the short term on the following questions [1]:

(1) Which requirements are to be applied to the minimum burnup of fuel elements with regard to the different management steps?

(2) Which plutonium vector should be envisaged for irradiated uranium and MOX fuel elements, taking into account safety and security requirements?

In accordance with the agreements between the German power utilities and the reprocessing companies in other European countries, the plutonium recovered during reprocessing in the form of mixed oxide (MOX) would have to be used, as stated by the BMU in [1], in nuclear power plants in Germany. This use would require a certain time window to ensure complete utilisation of the plutonium accumulating until the end of the use of nuclear energy in Germany.

3 Consultations

At its 18th meeting on 27.05.2011, the ESK dealt with related issues. After discussion, the ESK adopted the following statement.

4 Assessment basis

The basis for the safety assessment of the management of spent fuel from power reactors by the ESK is the Atomic Energy Act [2], in particular the proof required according to § 7 (2) of the Atomic Energy

Act that the necessary precautions have been taken in the light of the state-of-the-art of science and technology to prevent damage. The radiological protection objectives of the necessary precautions are specified in the Radiation Protection Ordinance [3].

Further general assessment criteria for partial steps of spent fuel management are

- the RSK recommendation “Safety Guidelines for Dry Interim Storage of Irradiated Fuel Assemblies in Storage Casks” [4], and the
- “Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste” [5].

A basic criterion for the assessment to be performed is that all aspects regarding the

- **safety** (ensuring the safety of spent fuel, especially to prevent the release of radioactive material, radiation shielding, and ensuring subcriticality),
- **security** (ensuring the safety of spent fuel against unauthorised interference by third parties and against theft), and
- **safeguards** (fissile material flow control – ensuring non-diversion for military use, here, in particular, compliance with the relevant provisions within the framework of the Non-Proliferation Treaty to which the Federal Republic of Germany committed itself)

are taken into account.

A comparison of “immediate shutdown” with spent fuel management after reaching the “target burnup” is required under all three aspects of safety, security and safeguards. In this context, “target burnup” is defined as the state resulting if a fuel element completely goes through its intended operating cycles and thus reaches the burnup per design. The state of “immediate shutdown” is characterised by the fact that a number of nuclear power plants currently shut down will not be started up again. Thus, a part of their fuel elements remains in the state of lower burnup compared to the “target burnup”. The comparison is made taking into account the question whether there will be an increase in the risks by the “immediate shutdown” compared to shutdown when reaching the “target burnup”.

5 Statement

5.1 Background

5.1.1 Background regarding the management of fuel elements from nuclear power plants

After the last irradiation, the fuel elements have to go through the following steps:

- After shutdown, the fuel elements are still in the reactor pressure vessel while the operation of the necessary safety systems of the reactor (e. g. cooling systems for residual heat removal, maintenance of a subatmospheric pressure in the reactor building, monitoring systems) has to be continued. The safety-related design is specific to the power plant type.

- Transfer into the wet storage facility. Once the connection to the fuel pool is established and flooded and the reactor pressure vessel is opened, the fuel elements can be transferred from the reactor into the storage pool by means of the refuelling machine. This process takes place regularly during refuelling. The transfer may only be effected some days after reactor shutdown. There are no limitations regarding longer residence times, since the fuel elements may principally also remain in the reactor pressure vessel for longer periods without additional safety problems.
- Storage in the wet storage pool. The transferred fuel elements are temporarily stored in the plant-internal fuel pool (wet storage facility) for some years. The fuel pool is located in the reactor building within the containment (in the case of pressurised water reactors) or in the reactor building but outside the containment (in the case of boiling water reactors). It is usually filled with fuel elements from refuelling in the previous years. In this respect, it is stipulated in the operating licence of each nuclear power plant that at least that number of fuel element positions in the fuel pool is to be kept free which allows transfer of the complete reactor core into the fuel pool at any time. For operating the fuel pool and ensuring its safety, operation of the necessary safety systems (e. g. cooling systems for residual heat removal, maintenance of a subatmospheric pressure in the reactor building, monitoring systems) also has to be continued after reactor shutdown. When the fuel elements are removed from the fuel pool, some of these safety systems may be taken out of service. The safety-related design is specific to the power plant type. The time for the retention of fuel elements in the fuel pool is not limited in the existing operating licences.
- Transfer into interim storage casks. In the fuel pool, the fuel elements can be transferred into casks for transport or casks for dry interim storage (e. g. CASTOR®). These casks are already sealed inside the reactor building and compliance with licence requirements (i. a. regarding leak tightness) is checked. The casks are then removed from the reactor building. The transfer of the fuel elements from the fuel pool into the casks can take place when the boundary conditions of the cask qualification and the technical acceptance criteria of interim storage facilities are complied with. Relevant restrictions result, in particular, from the residual heat still released, the requirements concerning subcriticality and the strengths of the gamma and neutron radiation resulting in the gamma and neutron dose rate at the cask surface. Typically, the design values for interim storage casks are reached after a decay period of about five years after shutdown and removal of the fuel elements from the reactor.
- Interim storage in the cask storage facility. The storage casks removed from the reactor building are transported to a dry storage facility that is located at the respective power plant site. The dry storage facility is a facility that is separated from the plant in terms of safety, fulfilling the requirements according to [4]. The removal of the decay heat of the cask inventory in the dry storage facility takes place without active components passively by the outside air passing through natural convection and by heat radiation. Therefore, no energy and cooling water supply is required for maintaining the removal of decay heat. The facilities and the casks are protected against massive external events, even against the crash of a large aircraft and subsequent fuel fire. The interim storage facilities are licensed for 40 years of operation. The existing interim storage facilities are already partially occupied with filled storage casks. However, the total capacity of

each storage facility is designed such that – based on the residual electricity volumes stipulated in the Atomic Energy Act of 2002 – all fuel elements from the operation of or the associated NPPs can be emplaced and that there is also some spare capacity.

- Preparation for disposal. Depending on the intended disposal concept (see below), the fuel elements have to be removed from the interim storage casks, conditioned and filled into the package for disposal (disposal container, disposal canister). These processes are carried out by remote control in a facility with a correspondingly large hot cell. The pilot conditioning plant (PKA) in Gorleben is such a facility. As an alternative to repackaging, it is being examined whether the interim storage casks can directly be used as disposal containers, this would make repackaging unnecessary.
- Disposal. Disposal will be realised in a repository mine for spent fuel elements and high level waste. As things stand today, it is envisaged that all fuel elements and high level waste accumulating from the operation of the German nuclear power plants will be emplaced in this repository. The location and the technical design for this repository have not been determined definitely yet. However, the Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste [5] already include the basic requirements. The concepts currently under discussion that are to fulfil these requirements are either based on the approach of storing unsegmented fuel elements or fuel rods. These will be either packaged in a thick-walled disposal container or in a disposal canister. The direct use of interim storage casks as disposal containers is also being examined. The disposal containers are intended for drift emplacement, the disposal canisters are intended for emplacement in bore holes within the repository mine. Emplacement in a repository can begin when the repository is built and put into operation. Today, a time span of about 30 to 60 years is assumed for the actual emplacement operation.

5.1.2 Background regarding the burnup at the nuclear power plants affected by the moratorium

The nuclear power plants listed in the following Table 1 are currently under discussion regarding a permanent cessation of operation. In these nuclear power plants, there are fuel elements, some of which have only been irradiated between 11 and 300 full-load days. The plants KKK and KKB have already been temporarily shut down for many months; the last operating cycles amounted to 11 and 29 full-load days, respectively.

Type	Plant	Location	Max. enrichment acc. to licence	Last refuelling outage	No. of new FE	NPP shut down on
BWR	KKB	Brunsbüttel	4.02%	11.04.-02.06.07	76	18.07.07
BWR	KKK	Krümmel	4.00%	04.-26.08.07	104	04.07.09
PWR	KKU	Unterweser	4.40%	07.-30.08.10	40	19.03.11
PWR	KWB-A	Biblis	4.00%	17.09.-21.10.10	44	19.03.11
PWR	KWB-B	Biblis	4.00%	11.11.-07.12.10	92	26.02.11
BWR	KKP-1	Philippsburg	4.40%	12.04.-14.05.10	112	16.03.11
PWR	GKN-1	Neckarwestheim	4.40%	25.10.-23.12.10	40	16.03.11
BWR	KKI-1	Isar	4.70%[1]	10.09.-24.10.10	136	18.03.11

Table 1: Survey of the nuclear power plants that might be decommissioned permanently

Thus, the burnup of the fuel elements inserted during the last refuelling is in the range of a few hundred (KKB, KKK) to a few thousand MWd/t_{HM}. This means that, compared to the target burnups of 40,000 to about 65,000 MWd/t, the burnups achieved are significantly lower. This has an impact on various physical properties of these partially spent fuel elements:

- After a relatively short decay time, residual heat production and gamma source strengths are lower.
- The neutron source strength is lower because there are less (α, n) reactions and less spontaneous fissions.
- The content of fissile uranium-235 is higher because the uranium-235 existing originally was only partly consumed by fission.
- For uranium fuel elements, the content of plutonium is lower because less plutonium was built up due to the shorter residence time in the reactor.
- The isotopic composition of the plutonium built up shows a higher percentage of Pu-239 than plutonium from fuel elements with higher burnup.

Moreover, it is to be noted that some of these partially spent fuel elements do not have the minimum burnup required for current cask licences.

5.1.3 Background regarding the use of mixed oxide fuel elements in nuclear power plants

In the past, a part of the fuel elements from the operation of German nuclear power plants was reprocessed. The transport for reprocessing was carried out for the last time before 01.07.2005 in accordance with the stipulations in § 9a (1) of the Atomic Energy Act.

[1] This is a maximum value averaged over all fuel rods of a fuel element in the enriched part. The enrichment averaged over an entire fuel element is lower.

During reprocessing, in addition to uranium, the plutonium produced is separated; it is to be taken back by the respective nuclear power plant operator according to contractual provisions and, in accordance with § 9a of the Atomic Energy Act, it is to be utilised without detrimental effects or to be delivered to third parties within the European Union or Switzerland for non-detrimental utilisation.

The proof of non-detrimental utilisation is currently being furnished through the use of MOX fuel elements in German nuclear power plants.

Licences for the use of MOX

The situation regarding the licence for the handling of MOX is shown in the following tables.

- The following NPPs have been granted a licence for the use of MOX and use MOX:

	MOX FE per refuelling		Max. amount of MOX in the core		Max. share of MOX FE in the core (%)
	No.	t_{HM}	No.	t_{HM}	
PWR Brokdorf	16	8.5	64	34.1	33
PWR Isar 2	24	12.7	96	50.9	50
PWR Neckarwestheim 2	24	12.8	72	38.4	37
PWR Philippsburg-2	20	10.6	96	50.9	37
BWR Gundremmingen B	68	11.8	300	52.2	38
BWR Gundremmingen C	68	11.8	300	52.2	38
PWR Emsland	12	6.4	48	25.6	25

Table 2: Plants with a licence for the use of MOX that use MOX fuel elements

- The following NPPs have been granted a licence for the use of MOX but currently do not use MOX:

	MOX FE per refuelling		Max. amount of MOX in the core		Max. share of MOX FE in the core (%)
	No.	t_{HM}	No.	t_{HM}	
PWR Grohnde	16	8.5	64	34.1	33
PWR Unterweser	24	8.5	64	34.1	33
PWR Grafenrheinfeld	16	8.5	64	34.1	33
PWR Neckarwestheim-1	16	5.7	16	5.7	9

Table 3: Plants with a licence for the use of MOX but currently not using MOX fuel elements

- At present, the following NPPs do not have a licence for the use of MOX: Biblis Units A and B, Brunsbüttel, Krümmel, Philippsburg-1 and Isar-1

Accordingly, none of the currently shut down nuclear power plants stated in Table 1 uses MOX, but only plants that are expected to be in operation a few years longer.

Current and planned use of MOX

According to the information provided by the BMU, the status of the actual use of MOX is as follows (information and data as at 31.12.2009 are exact, information and data as at 31.12.2010 are only preliminary[1]):

- Of the total amount of fissile Pu 239 and Pu 241 (Pu_{fiss}) to be considered, an amount – as at 31.12.2009 – of approximately 31,700 kg (as at 31.12.2010 approximately 32,300 kg Pu_{fiss}) is or was used in German nuclear power plants. In 2009, fresh MOX fuel elements were inserted in the nuclear power plants Philippsburg 2, Brokdorf, Isar 2, Gundremmingen B and C as well as Emsland.
- There remains an amount – as of 31.12.2009 – of approximately 5,700 kg Pu_{fiss} (as at 31.12.2010 approximately 5,000 kg Pu_{fiss}) that still has to be utilised without detrimental effects.
    - 592 + 264 = 856 kg Pu_{fiss} of it are available in the form of MOX fuel elements already fabricated for use.
        - For 2011, use of fresh MOX fuel elements is scheduled as follows:
            - KKI-2: 12 MOX FE, 294 kg Pu
            - KKE 12 MOX FE, 298 kg Pu
            - Use of fresh MOX fuel elements in 2011: **592 kg Pu**
        - For 2012, use of fresh MOX fuel elements is scheduled as follows:
            - KKI-2 12 MOX FE, 294 kg Pu (calculated)
            - KWG 16 MOX FE, 264 kg Pu (delivery from GB)
            - Use of fresh MOX fuel elements in 2012: **558 kg Pu**
    - Approximately 3,600 kg Pu_{fiss} of it will be available in the next year in a form usable in MOX fabrication.
    - Approximately 1,200 kg Pu_{fiss} of it are not yet available in a form that can be used in MOX fabrication (due to the fact that a residual amount of spent fuel elements of approximately 170 t_{HM} still has to be reprocessed at the Sellafield reprocessing plant).

[1] Larger values are rounded up to full 100 kg.

The scheduled use of fresh MOX fuel elements from 2013 to 2019 is shown in the following table (the amounts of Pu_{fiss} are calculated):

NPP	Year	MOX FE	Pu_{fiss} (kg)	
KKI-2	2013	12	294	
KBR	2013	12	250	
KKI-2	2014	12	294	
KBR	2014	12	250	
KBR	2015	12	250	
GKN-2	2016	16	377	
GKN-2	2017	12	283	
KKE	2017	12	297	
KRB-B/C	2018	112	865	
KKE	2018	12	297	
KKE	2019	4	99	**Total: 3.600 kg Pu_{fiss} approx.**

Table 4: Scheduled use of fresh MOX fuel elements in German nuclear power plants

In total, the use of MOX from 2011 to 2019 will amount to approximately 4,800 kg of plutonium. The residence time of the MOX fuel elements in the reactor core is generally four to five years.

5.2 Assessment of the management steps for fuel elements with lower burnup regarding capacities, minimum burnup and plutonium vector

5.2.1 Fuel elements in the reactor building

In this respect, the steps “staying in the reactor”, “transfer into the wet storage pool”, “storage in the wet storage pool” and “transfer into interim storage casks” are to be considered. Common to all steps is that the systems and buildings of the reactor and the power plant ensure safety.

Regarding the storage capacity, the following is to be stated:

- It is stipulated in the operating licence of each nuclear power plant that that number of fuel element positions in the fuel pool is to be kept free which allows immediate transfer of the complete reactor core into the fuel pool at any time. Regarding the storage capacity, this means that for the nuclear power plants in question, transfer of the fuel elements into the wet storage pool has to be feasible at any time. When comparing “immediate shutdown” with “target burnup”, in this respect the situation remains the same.

Regarding safety in the context of storage, the situation is to be assessed as follows:

- The necessary cooling capacity for the wet storage pool is available. The cooling system is designed for a heat output resulting from a longer irradiated core, just unloaded from the reactor (with a decay time in the order of four days) and, in addition, a loading of all fuel element positions remaining then with older spent fuel elements. The largest share of heat output comes from the just unloaded core. Since in the case of a definitive shutdown after the moratorium, a decay of the residual heat will already have taken place for several months, a lower cooling capacity is required than given per design.

- Regarding criticality safety, the wet storage pools are designed such that even a considerable number of fresh fuel elements can be stored in the storage racks. This is normally required because fresh fuel elements will first have to be transferred into the wet storage pool before inserting them in the reactor. The storage racks are therefore constructed using borated materials (boronised steel or boron carbide) that ensure subcriticality also under these conditions. Since the partially spent fuel elements to be unloaded involve less stringent requirements regarding the maintenance of subcriticality compared to fresh fuel elements, criticality safety is ensured in every case.
- The protection against external and internal hazards and against cooling failure is ensured by the same structural measures and safety systems as in the case of "target burnup".
- Thus, when comparing "immediate shutdown" with "target burnup", the situation remains the same in terms of safety.

Regarding safety during transfer "reactor – fuel pool" and "fuel pool – interim storage cask", the following applies:

- The facilities for transfer and the transfer processes are designed such that both fresh fuel and fuels of different burnups can be handled. This also ensures safety during handling of the partially spent fuel elements concerned now. The situation regarding the safety of dry storage casks is dealt with below.

Regarding security, the situation in the case of "immediate shutdown" is basically the same as for "target burnup":

- The security measures refer to the protection of the reactor building; since all processes considered here take place within this building, there is no difference regarding effectiveness and security requirements between "immediate shutdown" and "target burnup".
- Moreover, partially spent fuel elements with the irradiation times to be considered here of some weeks as a minimum also have a high level of intrinsic radiation due to their content of fission products. Handling without shielding is therefore not possible. Thus, actions such as e.g. theft cannot be carried out without attracting attention.

Regarding fissile material flow control, the situation, according to current practice, is as follows:

- For fissile material monitoring, the movement of fuel elements in the reactor building is monitored using different methods; each fuel element represents the unit with known contents of fissile material that is to be monitored under safeguard aspects. Every movement made with fuel elements can be seen by means of instrumental safeguards monitoring. The burnup of the fuel does not matter in this respect.
- When loading storage casks, the fuel elements loaded will be clearly identified and recorded in balance sheets. After closure and sealing of the cask, it represents the unit to be monitored under safeguard aspects since the inventory in the sealed cask placed under video monitoring cannot be changed and cask movement cannot take place without being noticed.

5.2.2 Fuel elements in interim storage casks

In this respect, the steps “transport from the reactor building to the interim storage facility”, “storage in the interim storage facility” and “removal for preparing disposal” are to be considered. Common to all steps is that the fuel elements are located in massive sealed interim storage casks. Safety is ensured by the casks.

Regarding the storage capacity, the following is to be stated:

- The capacities of the interim storage facilities at the nuclear power plants are designed such that they can accommodate all fuel elements that accumulate within the frame “phase-out schedule” applicable until 07.12.2010 and an additional buffer amount. Since the regulation now under discussion leads to a shutdown, depending on the plant (Table 1), at the same time as or earlier than originally planned, there are sufficient interim storage capacities available for each nuclear power plant in question. Compared to “immediate shutdown” with the "target burnup" there will be either no other situation or a bit more favourable condition.

As regards dry storage of spent fuel elements in casks, fulfilment of the four fundamental safety functions:

- safe enclosure of the radioactive substances,
- stable decay heat removal,
- maintenance of subcriticality,
- avoidance of unnecessary radiation exposure, limitation and control of the radiation exposure of the operating personnel and the population

is mainly ensured by the design of the thick-walled metallic casks. In the licensing procedures of the different interim storage facilities, fulfilment of the safety functions for each fuel element/cask combination applied for was verified and laid down in the respective Technical Acceptance Criteria of the storage facilities. The specification values laid down in the Technical Acceptance Criteria relate both to the casks as a whole (e. g. total thermal output) and cask components (e. g. tightness of the individual barriers) as well as to the individual fuel elements (e. g. enrichment or minimum burnup). Within the framework of the licensing procedures, fuel elements were generally taken into consideration whose combination of enrichment, burnup and decay time lead to thermal outputs and source strengths (gamma and neutrons) with the highest possible degree of coverage. With these fuel elements, the safety proofs were then furnished on the basis of homogeneous or heterogeneous loading variants. However, particularly with regard to shielding, individual proofs on source strengths were applied for, reviewed and approved.

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The following addresses the essential aspects generally considered from the point of view of safety and licensing, regardless of whether these have already been approved in the individual on-site interim storage facilities or not.

Regarding safety during storage, the situation is to be assessed as follows:

- Regarding the cooling of the loaded casks, the maximum decay heat generation is to be considered. Loading of a cask is only permissible if the entirety of the fuel elements in the respective cask remains below this decay heat generation. In addition, the maximum thermal output of each fuel element is limited, depending on their position in the cask basket. For fuel elements not having reached their target burnup yet, the decay heat generation is less for the same decay time.
- The shielding properties of the casks (and the inventories) define the maximum gamma and neutron source strength that can be loaded into a cask or a position of the fuel basket with which the maximum permissible dose rate (gamma and neutrons) at the cask surface is reached. In this respect, the licences generally include respective proofs on the source strengths furnished on a case-by-case basis. For fuel elements not having reached their target burnup yet, both the gamma and the neutron source strengths are lower for the same decay time.
- Regarding criticality safety, the storage casks may only be loaded such that subcriticality including the specified margins is ensured. The existing storage licences generally require a minimum burnup of about 10,000 MWd/t_{HM} for fuel elements with initial enrichment higher than 4%. The current cask certifications require a minimum burnup of 12,000 MWd/t_{HM} for PWR fuel elements with initial enrichment higher than 4%.
- To enable loading with fuel elements not having reached the minimum burnup yet, modifications of the certifications and storage licences are required or the possibility of furnishing individual proofs to be provided. Technical measures could be, for example, loading of the casks with fuel elements with different burnup and enrichment levels and partial loading of casks. From the point of view of the ESK there are no technical reasons that would speak against this approach. This would however require that the respective licensing or certification procedures are performed quickly.
- Protection against external hazards is ensured by the massive casks and the structural design of the interim storage facility. This also applies to the crash of a large aircraft with subsequent fuel

fire. Respective proofs were furnished in the licensing procedures for the individual interim storage facilities.

Regarding security, the situation in the case of “immediate shutdown” is basically the same as for “target burnup”:

- The security measures refer to the protection provided by the casks and the protection of the site of the interim storage facility. In this respect, there is no difference regarding effectiveness and security requirements between “immediate shutdown” and “target burnup”.
- The mass of the cask in the order of 100 Mg prevents theft without attracting attention.
- The theft of individual fuel elements from the locked storage casks at the on-site interim storage facilities is technically not feasible. Moreover, the high level of intrinsic radiation of the fuel elements with higher burnup also ensures a high self-protection in case of mixed loading. However, this would require an amendment of the valid storage licence, which currently requires a minimum burnup of 3.000 MWd/t_{HM} for each fuel element.

Altogether, there is no difference between partially spent fuel elements and fuel elements with “target burnup” regarding security and its effectiveness if the partially spent fuel elements are filled in as part of mixed loading together with spent fuel elements.

Regarding the safeguards, the situation is as follows:

- The sealed cask represents the unit to be monitored under safeguard aspects since unloading of individual fuel elements from the sealed cask without being noticed is not to be postulated due to the safeguard measures implemented. The movement of the casks is monitored and each cask identified for storage and transport. This situation remains the same, regardless of whether the casks are loaded with fuel elements with target burnup or partially spent fuel elements.

5.2.3 Preparation for disposal

Depending on the intended disposal concept, the fuel elements have to be removed from the interim storage casks, conditioned and filled into the package for disposal (disposal container, disposal canister). For reasons of radiation protection, this has to be done in a conditioning facility with a large hot cell.

With regard to this step, which takes place not until a few decades after loading of the interim storage casks, the question arises whether the fuel elements unloaded from the interim storage tanks casks are in a condition in which they can be handled without any significant difficulties. In particular, their mechanical integrity (manageability) must have been maintained and a systematic failure of the fuel rods must be avoided.

Comparing partially spent fuel elements with fuel elements with target burnup it is to be noted that the partially spent fuel elements have experienced less loads. This includes shorter residence times in the reactor and less irradiation of the cladding tubes. For this reason, damages regarding the mechanical integrity of partially spent fuel elements are less probable than for fuel elements with target burnup.

Regarding criticality safety in the repository, the casks and canisters used for disposal may only be loaded such that subcriticality including the specified margins is ensured. To enable loading with fuel elements not having reached the minimum burnup yet, mixed loading or partial loading or other measures (e. g. addition of depleted uranium) might be required. From the point of view of the ESK there are no technical reasons that would speak against this approach.

Regarding security and safeguards, there is no difference in the requirements and implementation between partially spent fuel elements and fuel elements with target burnup.

5.2.4 Disposal

The existence of partially spent fuel elements has practically no influence on the required capacity of the repository. In addition, the earlier shutdown of nuclear power plants now under discussion leads to a lower amount of spent fuel that has to be emplaced in a repository.

Regarding safety in the context of disposal, the situation is to be assessed as follows:

- Regarding heat input from the disposal packages, the maximum permissible decay heat generation is to be observed resulting from the maximum permissible temperature increases at the host rock boundary surface. This can be achieved by a correspondingly adapted prior interim storage time and by the emplacement geometry (e. g. spacing between the disposal packages). Here, partially spent fuel elements with their lower thermal output involve less stringent requirements than fuel elements with target burnup.
- Regarding criticality safety, the storage areas may only be filled such that subcriticality including the specified margins is ensured. This may require mixed loading or partial loading. From the point of view of the ESK there are no technical reasons that would speak against this approach. What measures have to be realised technically to ensure subcriticality still requires further investigation.

Security and safeguards for the operation of the repository have to be realised integrally for the entire facility. In this respect, there is no difference in the requirements and implementation between partially spent fuel elements and fuel elements with target burnup.

The current repository concept raises the question of whether future generations want to recover the U-238 and U-235 (more than 10,000 t) and the plutonium (more than 100 t) from the emplaced spent fuel elements as raw material. For a repository which can also accommodate fuel elements with low burnup, there will be in addition more than 100 tons of uranium with an enrichment of 3-4% U-235 and an amount of a few tens of kilograms of plutonium with a very favourable plutonium vector for weapons.

To make such future recovery extremely difficult, technical options are conceivable in the repository (e.g. a targeted distribution of individual quantities). In this respect, it is also to be noted that such measures can be implemented in a definitely sealed repository much easier than in a repository held open for retrieval, or even in an above-ground long-term interim storage facility.

In principle, there is still the possibility to reprocess fuel elements with very low burnup from plants with very short or short period of operation, or to continue burnup of these fuel elements, possibly also in other plants.

5.2.5 Assessment regarding the non-detrimental utilisation of the plutonium

Of the total amount of plutonium accumulated from the reprocessing of German spent fuel, a large amount - i.e. about 32,300 kg Pu_{fiss} – was used in MOX fuel elements. The amount still to be utilised is significantly smaller, namely approximately 5.000 kg Pu_{fiss}. The greater part of this amount (about 4,000 kg Pu_{fiss}) has already been included in the fabrication of further MOX fuel elements or will be included in the production in the near future.

The scheduled residence times and power plants using these MOX fuel elements show the following:

- The use of MOX fuel elements is no more intended in any of the power plants affected by the moratorium.
- The nuclear power plants concerned plan the last use of fresh MOX fuel elements, depending on the plant, by 2019 at the latest (see Table 4).
- Thus, utilisation of the plutonium now available for the fabrication of MOX fuel elements is ensured as far as use (fabrication and transport) will be feasible as scheduled.

Regarding the plutonium not yet separated in Great Britain, the following possibilities exist:

- For the fuel elements not yet reprocessed, the reprocessing contracts will be terminated and the spent fuel elements will be returned to a German interim storage facility (40 containers approx.).
- If reprocessing will be performed, additional 600 kg Pu_{fiss} will have to be treated.
  - These can be used in case of timely availability in German nuclear power plants in the form of MOX fuel elements.
  - According to the provisions in § 9a (1c) of the Atomic Energy Act, remaining quantities may e.g. also be given to other nuclear power plant operators in the EU or in Switzerland.

- Finally, there is in principle also the possibility to condition plutonium for a repository, e.g. in the form of so-called storage rods or storage elements. In this respect, special provisions are to be ensured for physical protection and criticality safety.

The choice of the way and the conclusion of such contracts is subject to the decision of the respective operator.

6 Answers to the BMU questions

6.1 "Which requirements are to be applied to the minimum burnup of fuel elements with regard to the different management steps?"

In the nuclear power plants decommissioned following the moratorium, fuel elements are used due to the shutdown that so far had only been used between 11 and 300 full-load days in addition to fuel elements already in use for a longer period. These fuel elements have a comparatively low burnup. In these fuel elements, however, so many fission products have already built up that they can only be handled under the same protective measures against radiation as fuel elements with higher burnup.

Chapter 5.2 of this statement examined the different waste management steps in detail to determine how these will be regarding fuel elements with lower burnup. Altogether, it shows that in all steps "staying in the reactor", "transfer into the wet storage pool", "storage in the wet storage pool", "transfer into interim storage casks", "transport from the reactor building to the interim storage facility", "storage in the interim storage facility" and "removal for preparing disposal" as well as "disposal" the handling of spent fuel elements with low burnup is also technically feasible. As far as storage in the reactor and in the wet storage pool is concerned, this is covered by existing licences. The steps beginning with cask loading require the amendment of certifications and licences since the required minimum burnup is not reached. Regarding the interim storage casks and the disposal packages it is to be noted that here a mixed loading of fuel elements with higher and lower irradiation is possible in a manner that safe subcriticality can be ensured and the other safety parameters can also be met. Regarding the interim storage casks, corresponding modification licence procedures are required for the storage casks. From the point of view of the ESK, however, compliance with the licensing requirements can be achieved by appropriately defined mixed loadings. Since loading of the interim storage casks will only be possible after several years due to the decay storage required for all fuel elements, it is possible to perform and complete the necessary licensing procedures until then.

Regarding security and compliance with the safeguards (loading in the reactor and storage in the wet storage facility), there will be no other situation than for fuel elements having reached the target burnup. For interim storage, the licences will have to be adapted. From the point of view of the ESK, the technical requirements can be covered by mixed loading. Regarding disposal, additional challenges will arise to the additional plutonium with a high percentage of Pu-239.

6.2 "Which plutonium vector should be envisaged for irradiated uranium and MOX fuel elements, taking into account safety and security requirements?"

In the nuclear power plants decommissioned following the moratorium, fuel elements are used that so far had only been used between 11 and 300 full-load days due to the shutdown in addition to fuel elements already in use for a longer period. In these fuel elements, plutonium has already been generated; this plutonium has another plutonium vector compared with fuel elements having reached the target burnup (plutonium isotope ratios). There is a comparatively higher content of Pu-239.

Regarding safety, there will be no differences, as examined in detail in Chapter 5.2.

The plutonium vector plays a role particularly regarding the question, how easy military weapons can be produced. Basically, it is easier to make nuclear weapons from plutonium with a higher content of Pu-239.

However, the international fissile material monitoring makes no distinction between fuel elements with different burnup and correspondingly different plutonium vectors. Thus, regarding the fuel elements considered here, there will be no difference in terms of the safeguards.

Regarding security, there will be no significant changes for the steps prior to disposal if assuming mixed loading of the casks. For disposal it is to be noted that with the emplacement of some tens of kilograms of plutonium with a high percentage of Pu-239, special challenges arise regarding the protection against retrieval.

6.3 Time window for plutonium utilisation

Of the total amount of plutonium accumulated from the reprocessing of German spent fuel, a large amount - i.e. about 32,300 kg Pu_{fiss} – was used in MOX fuel elements. The amount still to be utilised is significantly smaller, namely approximately 5.000 kg Pu_{fiss}. The greater part of this amount (about 4,000 kg Pu_{fiss}) has already been included in the fabrication of further MOX fuel elements or will be included in the production in the near future.

The scheduled residence times and power plants using these MOX fuel elements show the following:

- The use of MOX fuel elements is no more intended in any of the power plants affected by the moratorium.

- The nuclear power plants concerned plan the last use of fresh MOX fuel elements, depending on the plant, by 2019 at the latest (see Table 4).
- Thus, utilisation of the plutonium now available for the fabrication of MOX fuel elements is ensured as far as use (fabrication and transport) will be feasible as scheduled.

Regarding the remaining quantities that might accumulate due the strongly delayed fulfilment of the reprocessing contracts in Great Britain, there are various possible solutions that are explained more detailed in Chapter 5.2.5.

7 Documents

[1] Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
Letter of Federal Minister Dr. Röttgen of 13.05.2011 to the ESK Chairman

[2] Atomic Energy Act (AtG) of 23.12.1959
Act on the Peaceful Utilization of Atomic Energy and the Protection against its Hazards (Federal Law Gazette I, p. 814), as amended and promulgated on 15 July 1985 (Federal Law Gazette I, p. 1565), last amendment by the 12th Act amending the Atomic Energy Act of 8 December 2010 (Federal Law Gazette I, p. 1817)

[3] Radiation Protection Ordinance
Ordinance on the Protection against Damage and Injuries Caused by Ionizing Radiation (Radiation Protection Ordinance – StrlSchV) of 20 July 2001 (Federal Law Gazette I, p. 1714), as last amended by Article 2 of the Act of 29 August 2008 (Federal Law Gazette I, p. 1793)

[4] RSK recommendation
Safety Guidelines for Dry Interim Storage of Irradiated Fuel Assemblies in Storage Casks; 05.04.2001

[5] Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste
as at 30. September 2010