Burnup Credit in Spent-Fuel Transport to COGEMA La Hague Reprocessing Plant

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INTRODUCTION

As consignor on behalf of COGEMA, Nuclear Transport Limited (NTL) is in charge of spent-fuel transports from European power plants (excluding Eléctricité de France) to the COGEMA reprocessing plant at La Hague. NTL has carried out the transport operations since the early 1970s; this now represents more than 2,380 movements to COGEMA (about 20,400 fuel elements and 5,516 t of uranium) from 29 reactors spread throughout Europe. For this purpose, NTL operates a wide range of transport casks of several designs with a capacity varying from 3 PWR fuel assemblies to 12 PWR or 32 BWR fuel assemblies for the larger cask designs. Spent-fuel transport casks are designed always to be subcritical throughout the transport cycle, including the unloading operations at the reprocessing plant. Subcriticality is accomplished by the fuel support frame also known as "basket" which fits into the cask cavity. The role of the basket in terms of criticality is to ensure a well defined geometry as well as the removal of neutrons. This is achieved by a neutron poison distributed in the walls of the basket compartments. Casks are always loaded under water, but for transport two options are possible:"wet" casks have reactor pond water in direct contact with the fuel during transport while "dry" casks travel with a gas-filled cavity. Unloading at La Hague takes place in wet or dry conditions: however, in the first case the water is not poisoned by the addition of boron. During the unloading operations, the fuel assemblies are placed into racks which are transferred into a storage pond for a period of time, awaiting reprocessing. Storage racks are similar in design to cask baskets and perform the same function using the same means. The use of transport casks is subjected to package approvals issued by competent authorities. To obtain a package approval, a designer must demonstrate the subcriticality of the package under the most reactive conditions. The same applies to storage racks, which also require operating licenses. The most reactive conditions are achieved during the cask unloading, when the cavity is flooded with demineralised water and fuel elements are considered "fresh," that is, still having their initial enrichment in fissile material. However, this assumption is very conservative, as, during the irradiation process, the fuel elements use the major part of the initial fissile isotopes for power generation and therefore lose part of their reactivity.

On the other hand, the general trend in European power plants is to burn more and more reactive fuel elements with higher initial enrichment in fissile material, which allows higher final burnup and thereby more power generation per fuel element. For instance, the initial enrichment in ^{235}U of fuel elements available for transport and reprocessing from 1300 MWe German PWR power plants has increased from less than 3.3% in the beginning of the 1980s to about 3.5% in the mid-1980s and can now reach 4%. For this reason, the traditional assumption of considering fresh fuel for criticality assessments proved to be insufficient for the existing basket and storage rack designs to accommodate the new types of fuel elements that had to be transported and stored.

THE INITIAL SITUATION (1986)

Table 1 shows the initial capacities and criticality performances of several transport casks and baskets, calculated for fresh fuel: some of them were later on subjected to burnup credit assumption. For comparison, Table 2 indicates the acceptance limits per type of fuel assembly at the La Hague reprocessing plant and before the application of burnup credit.

TABLE 1
Cask licensing for transport without burnup credit

Type of cask	Type of basket	Type of fuel	Nr of basket compartments	Package approval for:	
				Nr of fuel elem.	Initial enr. ^{235}U
TN 13/1	904 or 924	16 x 16 array 230 mm square	12	11	≤ 3.31%
TN 13/2	904 or 924	16 x 16 array 230 mm square	12	11	≤ 3.31%
NTL 8/3	none	15 x 15 array 215 mm square	3	3	≤ 3.31%
NTL 11	3172	15 x 15 array 215 mm square	7	7	≤ 4.8%

TABLE 2
COGEMA La Hague limit of acceptance for fuel storage without burnup credit

Type of fuel	Limit of acceptance (fresh fuel) ^{235}U
200 mm square	≤ 3.70%
215 mm square	≤ 3.50%
230 mm square	≤ 3.30%

As shown in Table 1, despite a potential 12 compartments, the capacity of the TN 13 type casks equipped with a 904 or 924 basket was already limited to 11 fuel assemblies having a maximum initial enrichment in ^{235}U of 3.31%.

THE CURRENT SITUATION (1994)

First Step: Qualitative Burnup Checking

To cope with the increase of initial enrichment, it was decided to apply the "burnup credit" assumption for demonstration of the subcriticality of packages and fuel receipt facilities. A first step in the application of the burnup credit assumption was made in 1987 with the issue of the TN 13/1 and TN 13/2 package approvals [F/272/B(U) F Ca 1989][F/274/B(U) F B00 Rév.1 1987] for a content consisting of 11 PWR 16 x 16 array and 230 mm square fuel assemblies irradiated in 1300 MWe German reactors. A limited burnup credit of 3200 MWd/TU was considered in the safety assessment to extend the cask capacity to an initial enrichment in ^{235}U of 3.55%. A similar criticality study has been carried out on the NTL 8/3 type casks which decided on a higher figure of 5600 MWd/TU for the loading of 3 PWR 15 x 15 array and 215 mm square type fuel assemblies of 3.55% initial enrichment in ^{235}U [F/251/B(U) F C01 1989].

The acceptance of the burnup credit principle by the French Competent Authority has been subjected to several conservative conditions. Thus, for low burnup credit, both TN 13 and NTL 8/3 package approvals set out the following compensatory requirements:

(i) In order to ensure a safety margin on the irradiation, the allowed burnup credit must be reached on the least irradiated 50 cm of the fuel's active length instead of an averaged value over the total active length.

(ii) On the basis of its fuel management and in-core measurement records, the operator of the power plant must guarantee that the minimum burnup on the least irradiated 50 cm of the fuel's active length exceeds the allowed burnup credit.

(iii) The irradiation status of each fuel assembly must be checked by a qualitative go/no-go physical measurement in the reactor pond just before cask loading. These measurements are to be in accordance with the plant quality assurance policy.

In addition, the safety authorities required COGEMA and NTL to demonstrate the reliability of their fuel identification procedures.

Second Step: Qualitative Burnup Measurements

A second step in the application of the burnup credit assumption was made in 1993 for the transport and storage of the fuel assemblies with a 4% ^{235}U initial enrichment from the power plants of TIHANGE 1 (15 x 15 array and 215 mm square) and GROHNDE (16 x 16 array and 230 mm square). For the first case the burnup credit for the NTL 8/3 type cask has been raised to 9000 MWd/TU to meet the subcriticality criteria. In the case of the larger fuel assemblies, the existing baskets were not suitable, and a new high performance basket (type 928) has been designed for the TN 13/2 with a capacity of 12 elements of 4% ^{235}U initial enrichment, subject to a burnup credit of up to 12,000 MWd/TU in the most demanding loading configuration. Table 3 summarises the casks capacity after the application of the burnup credit assumption.

To compensate for the increase in burnup credit, a new requirement has also been introduced, which consists of replacing the qualitative irradiation go/no-go checking as previously performed by an independent quantitative measurement of the actual fuel burnup. The acceptance of each fuel assembly is now subjected to the comparison of the physical measurements with the minimum criteria and a cross-check with the utility-supplied data. To provide a safety margin, both package approvals specify that a minimum burnup value of 10,000 MWd/TU for the NTL 8/3 and 15,000 MWd/TU for the TN 13/2 has to be reached on the least irradiated 50 cm of the fuel's active length instead of an averaged value over the total active length as considered in the safety case [F/274/B(U) F-85 Dc 1994] [F/251/B(U) F Ea 1993].

To enable the storage of the high enriched fuel elements, the safety case of the storage racks has been revised in parallel, which leads to the acceptance limits presented in Table 4. The requirements from the safety authorities on irradiation are similar to the transport case (Table 3); i.e. (*) for 3200 MWd/TU and (**) for 10,000 MWd/TU (Prétesacque 1993).

IMPLEMENTATION OF BURNUP CREDIT

As mentioned before, the proportion of highly enriched fuel assemblies available in the storage ponds of the European reactors has been increasing over recent years. Several studies conducted in the USA (Sanders and Lake 1989) and in Europe (Prétesacque et al. 1992) concluded that the most credible source of operational error affecting burnup credit is the misloaded spent-fuel. The loading of an out-of-specification fuel element (i.e., a fuel element which fails to meet the package approval or the storage requirements) can be the result of two independent events: an error resulting from the preparation of the loading documents or an error during the cask loading at reactor site.

TABLE 3

Cask licensing for transport with burnup credit

Type of cask	Type of basket	Type of fuel	Nr of basket compartments	Package approval for: Nr of fuel elements	Initial enr. % ^{235}U	BU credit (safety case) MWd/TU	Condition
TN 13/1	904 or 924	16 x 16 array 230 mm squ.	12	11	≤ 3.55%	3200	*
TN 13/2	904 or 924	16 x 16 array 230 mm squ.	12	11	≤ 3.55%	3200	*
TN 13/2	928	16 x 16 array 230 mm squ.	12	12	≤ 4%	12,000	**
NTL 8/3	none	15 x 15 array 215 mm squ.	3	3	≤ 3.55%	5600	*
NTL 8/3	none	15 x 15 array 215 mm square	3	3	≤ 3.9%	9000	**
NTL 11	3172	15 x 15 array 215 mm square	7	7	≤ 4.8%	0	none

* Formal guarantee from the utility on the minimum burnup. Irradiation status checked by independent go/no-go physical measurement.

** Formal guarantee from the utility on the minimum burnup. Independent quantitative burnup measurement.

TABLE 4

COGEMA La Hague limit of acceptance for fuel storage with burnup credit

Type of fuel	Limit of acceptance % ^{235}U 0 MWd/TU	3200 MWd/TU	10,000 MWd/TU
200 mm square	≤ 3.70%	not defined	not defined
215 mm square	≤ 3.50%	≤ 3.75%	≤ 4%
230 mm square	≤ 3.30%	≤ 3.55%	≤ 4%

To meet the regulatory requirements and to enhance the global reliability of the fuel indentification for cask loading, the implementation of the burnup credit has led COGEMA and NTL to develop a system for fuel identification and burnup control which covers both documentary and operational aspects.

Documentary Aspect

A complete documentary system has been developed according to quality assurance principles between COGEMA and its contractual partners for the transport, storage, and reprocessing of the fuel assemblies (Prétesacque and Corny 1989). This documentary system ensures that the responsibilities are well defined between the reprocessor, the utilities, and the transporter. This aspect is of utmost importance as the fuel acceptance by COGEMA for storage and reprocessing and by NTL for transport is made on the basis of the utility-supplied data.

To evaluate the reprocessability of the fuel, the utilities supply COGEMA with all the necessary information including the pre-irradiation data (initial enrichments, fuel drawings etc.) and the post-irradiation data of each assembly (irradiation history etc.). Each parameter is checked in detail by comparison against the COGEMA acceptance criteria for storage and reprocessing and results in the issue to the consignors of an official list of fuel elements containing all fuel data with the formal acceptance or reservations from the reprocessor.

On the basis of this information, NTL designs the cask-loading plans and performs for each transport a careful verification of the package makeup against the limiting parameters of the cask safety report and the storage parameters of La Hague. When comparing data from Tables 3 and 4, it appears that the COGEMA limits of acceptance may differ from the transport limits. For instance, although the 215 mm square fuel assemblies having an initial enrichment of 3.75% are covered by the NTL 11 package approval at zero burnup, the fuel assemblies would require a minimum burnup of 3200 MWd/TU in order to comply with the storage licence of La Hague. Therefore, the transporter must take into account the most restrictive of both parameters in the preparation of the cask loadings (it would be pointless to transport fuel assemblies which could not be stored). The procedures in force between COGEMA and NTL ensure that the fuel which is loaded into the casks follows the most restrictive acceptance rule. At this stage, any non-conformance is raised with COGEMA, or treated internally in the case of NTL-designed casks, and the transport is postponed until the problem is solved. About 2 weeks before transport, on receipt of the fuel-pond positions and of individual burnup confirmation from the utilities (i.e., the formal guarantee on the least irradiated 50 cm of the fuel's active part), the cask-loading plans are prepared and checked by NTL.

All these actions are formally described throughout the quality system of each responsible department and result in formal records. The quality of the documentary system is periodically checked by internal and external audits carried out by COGEMA, NTL, or independant organizations. For instance, COGEMA has performed audits on several of its customers to ensure the reliability of the fuel-related data which are submitted for fuel analysis. NTL has been awarded an ISO 9001 certification for spent-fuel transport operations by the Lloyd's Register in UK and by TÜV in France and Germany.

Operational Aspects

The implementation of burnup credit has put emphasis on the fuel identification process and now imposes physical measurements on fuel assemblies prior to cask loadings. A reliability study on the fuel identification procedures used by COGEMA and NTL was carried out in 1987 in order to demonstrate to the French safety authorities that both parties had full control of the fuel identification process (Prétesacque et al. 1992). The study of the most likely failure scenarios enabled an improvement in the procedures by focusing on the prevention of misloadings and increasing the possibility of recovering errors prior to shipment. Since this study, the following actions have been implemented or almost completed:

- Fuel element preloading positions. The fuel assemblies selected for a given transport are set apart from the bulk of the stored fuel in the reactor pond. In order to facilitate identification and gripping of the fuel assembly, this area is positioned in a well defined part of the storage pond, which remains the same throughout the transport campaign. This also provides a preliminary fuel identification by the reactor staff.

- Training of the NTL operators in charge of the fuel identification on behalf of COGEMA with emphasis on the key points of the procedure. Each new technician is sent several times for training at reactor sites with experienced staff.
- Introduction of redundancy on fuel identification with low dependence level between operators.
- Written records of checks carried out on each action.
- Heightening of the reactor fuel handling staff awareness to fuel identification prior to transport.
- Segregation of fresh or low irradiated fuel assemblies.

Physical Measurements
According to the amount of burnup credit and the level of initial enrichment, two types of physical measurements are required prior to cask loading:

Qualitative Measurements
For limited burnup credit of less than 5600 MWd/TU for transport, for storage of 215 mm square fuel in the range of 3.50% to 3.75% ^{235}U, and for 230 mm square fuel in the range of 3.30% to 3.55% ^{235}U, only the irradiation status of the fuel assemblies has to be verified by "in line" measurements during the fuel transfer from its storage pond position to the cask compartments. The measuring technique consists of evaluating the gamma emission of each fuel assembly. A gamma detector equipped with a watertight probe is immersed into the fuel storage pond at a depth corresponding to the middle of the fuel's active part when handling the assemblies. The display is set up at a convenient place on the edge of the pond.

The measuring sequence starts with the verification of the calibration status of the equipment and background measurements. After the identification of a fuel assembly, it is taken from its storage pond position and transferred to the measuring area. The gamma dose rate values are recorded at a given distance between the axis of the fuel gripping tool and the axis of the probe. They are then compared with an acceptance criterion, and, if met, the fuel assembly is loaded into the cask.

The acceptance criterion is determined beforehand by numerous gamma dose-rate measurements as a function of the distance on a sample of high/low burnup fuel and short/long cooled fuel. The measuring equipment and its qualification curves are submitted to COGEMA for approval of the measuring parameters (i.e., minimum dose rate and distance). For instance, it is considered that a fuel element is irradiated if the dose rate measured at a minimum distance of 0.75 metre is higher than 100 mSv/h.

Quantitative Measurements
In the case of burnup credit exceeding 5600 MWd/TU for transport, for storage of 215 mm square fuel in the range of 3.75% to 4% ^{235}U, and for 230 mm square fuel in the range of 3.55% to 4% ^{235}U, a direct and quantitative measurement of the actual fuel burnup is required. For this purpose, two types of measuring equipment are available. The Python has been specifically developed by the CEA-Cadarache (Bignan et al. 1991) for passive and active fuel burnup and reactivity measurements and, the Fork Detector has been developed by the CEN-Mol (Carchon et al. 1994) which is based on the Ion 1-Fork designed by the Los Alamos Laboratory for safeguards applications. Both types of equipment are based on the same physical principle, which consists of passive measurements of neutrons emitted by the heavy nuclides contained in the irradiated fuel (by spontaneous fissions or (α, n) reactions). The design of the Python also features the possibility of active neutron measurements for the determination of the fuel-assembly reactivity by means of a ^{252}Cf neutron source: however, this possibility is not used for transport purposes. After calibration, the total neutronic emission is correlated to the fuel-assembly burnup. Several measuring points allow the determination of the axial burnup profile. The gamma emission is also

measured but is only used for confirmation of the fuel cooling time. These types of equipment are made of three main components:

(i) the detectors, which consist of two fission chambers and ionization chambers surrounding the fuel assembly;

(ii) the electronics for high voltage power supply and processing the signals delivered by the detectors. It also includes a PC computer for the global monitoring and display/printout of results; and

(iii) the mechanical part, which supports the detectors and ensures a well defined geometry during measurements.

The capability of each type of equipment to measure the fuel burnup has been assessed and formally approved by COGEMA. The technical support department of the French safety authorities have also been involved in the discussion on the measuring equipments.

After the identification of a fuel assembly, it is taken from its storage pond position and introduced into the measurement cell, which is either a dedicated storage pond position or a part of the measuring equipment. The input data concerning the selected assembly (cooling time, identification number, etc.) are then entered into the computer, and the burnup profile is recorded alongside the active part. The average value over the least irradiated 50 cm is calculated and compared with the acceptance criterion before final positioning of the fuel assembly into the cask or the preloading position in the pond storage rack.

In principle, the quantitative burnup measurements should be carried out "in line" in the cask-loading sequence of operations. However, in case of failure or sudden unavailability of the measuring equipment, the transport cask could stay partly loaded in the reactor pond, thus affecting the scheduling of the operations. In order to avoid this kind of situation, the quantitative measurements have so far been performed in separate batches of fuel elements, some time before the cask loading. In this case, the normal fuel identification procedure is completed by an additional qualitative irradation status checking performed "in line" on each fuel assembly before cask loading.

Responsibilities

The irradiation status and burnup measurements are performed under the responsibility of the reactors and controlled by the NTL technical assistants in charge of the fuel identification as COGEMA's representative at reactor site. After signatures of both parties, the dose-rate and burnup records are sent to COGEMA and NTL for information prior to cask despatch. The original of the records is attached to the transport documentation.

THE COGEMA / NTL EXPERIENCE

The first transport to COGEMA La Hague using burnup credit and qualitative measurements was performed from the power plant of Biblis (FRG) in 1987. Since this date, an ever growing number of fuel assemblies have been transported by NTL throughout Europe to La Hague with the benefit of the burnup credit assumption. The practice of qualitative burnup verification has since been implemented on the power plants of Biblis A, Isar 2, Grafenrheinfeld, Neckarwestheim 1, Unterweser, Philippsburg 2, Grohnde, Goesgen and Tihange 1 (this list does not take account of the Eléctricité de France power plants, some of which have also implemented such a technique). This now represents the transport of 1,664 fuel assemblies in 225 movements using casks of several designs: TN 13/1 and TN13/2, NTL 8/3, and NTL 11. In the latter case, the burnup credit rules are only applied for storage purposes at La Hague.

Since February 1993, the quantitative burnup measurement procedure has been implemented in the power plants of Tihange 1, Brokdorf, and Grohnde for the transport of fuel elements with higher initial enrichment, which to date represents the transport of 279 assemblies in 53 movements using the TN 13/2 and NTL 8/3 type of casks.

Since 1987, a large number of irradiation status and burnup measurements have been performed under the control of COGEMA and NTL at different power plants, using different measuring equipment. Records have shown that the results have always been well within the acceptance criteria and in accordance with the utility supplied-data, both in the case of dose-rate or direct burnup measurements.

At the same time, the records on the transport of more than 20,400 fuel assemblies showed no misloading (i.e., no loading of a nonapproved fuel element), thus demonstrating the reliability of the procedure used for the identification of the spent-fuel elements.

CONCLUSION

The continuous increase of fuel initial enrichment which is observed in the European power plants now imposes the use of the burnup credit assumption for transport and storage. The advent of transport and storage using burnup credit has put emphasis on the fuel identification and on the independent checking of the fuel burnup. According to the level of burnup credit required to achieve the subcriticality criteria throughout the transport and storage cycle, the fuel burnup is verified either by dose-rate or direct burnup measurements. The documentary and operational system developed by COGEMA and NTL for fuel transport, storage, and reprocessing ensures that all regulatory and safety requirements are met.

REFERENCES

Bignan G., Boschiero M., Poncelet F., Martin-Deidier L.,and Romeyer-Dherbey J., *Active and Passive Non-Destructive Measurements for Fuel Assemblies Nuclear Monitoring*, Proceedings from RECOD '91.

Carchon R., De Boeck W., Bergmans G., Bragard R., and Walrave C., *Fork Detector measurements on LWR Spent-fuel*. European Safeguards Research and Development Association (ESARDA) Bulletin (1994).

F/274/B(U) F B00 Rév.1, *Certificat d'Agrément d'un Modèle de Colis TN 13/2* (1987).

F/272/B(U) F Ca, *Certificat d'Agrément d'un Modèle de Colis TN 13/1*, (1989).

F/251/B(U) F C01, *Certificat d'Agrément d'un Modèle de Colis NTL 8/3* (1989).

F/274/B(U) F-85 Dc, *Certificat d'Agrément d'un Modèle de Colis TN 13/2* (1994).

F/251/B(U) F Ea, *Certificat d'Agrément d'un Modèle de Colis NTL 8/3* (1993).

Prétesacque P., *Fuel Acceptance Criteria with Respect to the Initial Enrichment*, COGEMA Branche Retraitement ref. A 1010 CA 006 Rév.0 (1993)(not published).

Prétesacque P. and Corny F., *Spent-fuel Acceptance for Transport and Reprocessing*., Proceedings of PATRAM '89 CONF-890631-vol.3, Washington, DC (1989).

Prétesacque P., Eid M., and Zachar M., *Reliability of the Fuel Identification Procedure Used by COGEMA During Cask Loading for Shipment to La Hague*, Proceedings of PATRAM '92 vol.3 p. 1580-1587, Yokohama (1992).

Sanders T.L. and Lake W.H., *Alternatives for Implementing Burnup Credit in the Design and Operation of Spent-fuel Transport Casks*, Proceedings of PATRAM '89 CONF-890631-vol.2 Washington, DC (1989).