RELIABILITY OF THE FUEL IDENTIFICATION PROCEDURE USED BY COGEMA DURING CASK LOADING FOR SHIPMENT TO LA HAGUE

P.Prétesacque [1] ,M.Eid [2] ,M.Zachar [3]

[1] Compagnie Générale des Matières Nucléaires, Vélizy, France.
[2] Commissariat à l'Energie Atomique, Gif sur Yvette, France.
[3] Nuclear Transport Ltd, Paris, France.

INTRODUCTION

As consignors, COGEMA and Nuclear Transport Limited (NTL) are in charge of spent fuel transports from the European power plants to the COGEMA reprocessing plant at LA HAGUE. Transports are shared between COGEMA and NTL in the following way:

- COGEMA-STS (Service des Transports Spéciaux) directly operates the transports from the Eléctricité de France (EdF) French power plants representing 50 reactors;
- NTL acts as a COGEMA sub-contractor and operates the transports fom all the other European power plants representing about 29 reactors.

For this purpose COGEMA-STS and NTL use a wide range of transport casks from several designers, with a capacity varying from 3 PWR fuel assemblies to 12 PWR or 32 BWR fuel assemblies. A transport cask for Light Water Reactor irradiated fuel mainly consists of a gamma and a neutron shielding made of steel or lead, which also provide containment, combined with resin. A basket containing the fuel assemblies fits into the cask cavity. A common characteristic of all the transport casks is the control of the criticality by the basket. This is achieved by the neutron poison, consisting of boron distributed in the walls of the compartments of the basket.The use of transport casks is subjected to package approvals issued by the competent authorities. These package approvals are supported by a safety report, partly based on a criticality assesssment, which defines the performance of the cask and its basket in terms of maximum fuel enrichment in fissile material.

Nowadays, European power plants are burning a very wide range of fuel assemblies and in order to optimise their plant management and operating cycles length, the actual trend is to use more and more reactive fuel with higher initial enrichment in fissile material. In the mid 80's the traditional assumption of "fresh fuel" used in evaluating criticality of the spent fuel casks proved to be insufficient for the existing basket designs to accommodate the new types of fuel assemblies that we had to transport. In order to extend the capability of their basket designs, COGEMA and TRANSNUCLEAIRE started to consider the new assumption of "burnup credit" for their criticality calculations thus reducing the amount of fissile material. For instance, it has been possible to increase the initial enrichment of the 16X16 KWU fuel type loaded in the 904 basket design from 3.3 % to 3.55 % of U235 with a limited burnup credit of 3200 MWd/TeU (TN 13/2 package approval).

This has been accepted by the French competent authority according to the philosophy of the consignor's responsibilities defined in the IAEA regulations (1985) and provided that :

- The fuel assemblies are burnt with a high safety margin with regard to the assumption of the safety case;
- The consignor verifies, according to quality assurance procedures, the irradiation status of each fuel assembly by a go-no go measurement (e.g. by gamma scanning) prior to loading in the transport cask;
- The consignor has a full control of the identification procedure of the fuel assemblies.

The purpose of this study was to quantify the reliability of the fuel identification procedure used to implement the third condition.

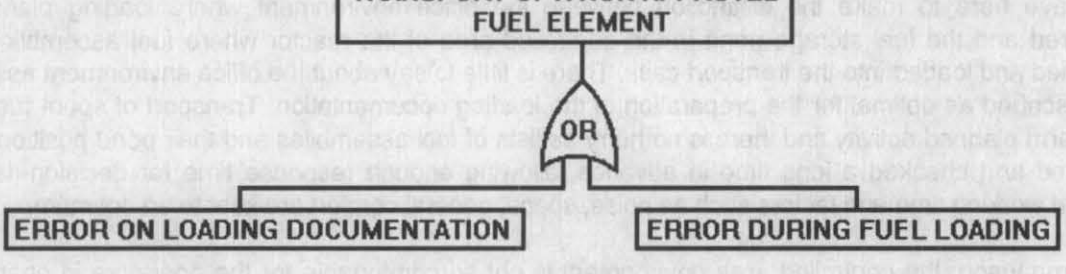
DEFINITION OF THE FAILURE STATE

The main event which could result in exceeding the fuel reactivity limits would be the loading of a nonspecification fuel assembly (Sanders and Lakes 1989). We therefore defined the failure state as being : "transport of a non-approved fuel assembly". Non-approved meaning that the fuel element is not the one intended to be loaded into the transport cask, and by extension it may be neither covered by the package approval nor accepted by the reprocessor.

SYSTEM ANALYSIS

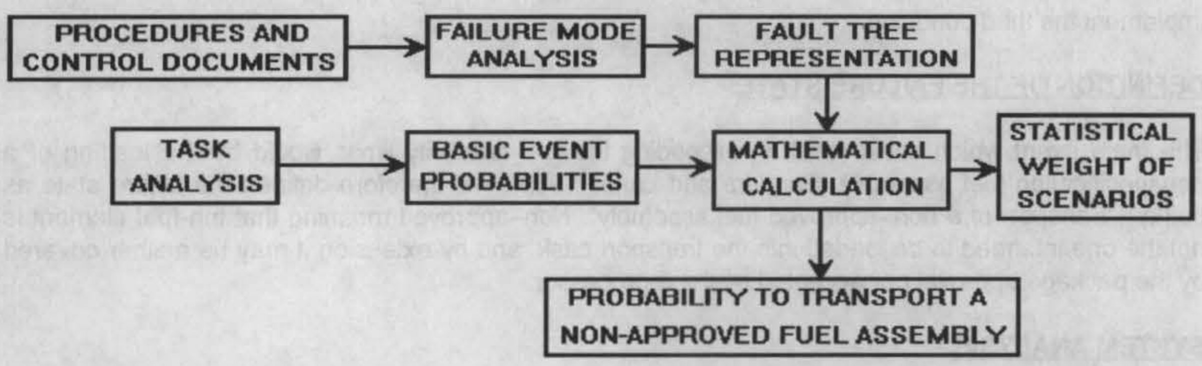
The process of fuel identification involves several parties linked by contractual arrangements (Prétesacque and Corny 1989). They are namely:
- The reactors, which issue the lists of fuel assemblies proposed for transport and reprocessing;
- The reprocessor (COGEMA), which accepts the proposed lists with possible reservations in accordance with its internal acceptance criteria. Reservations may concern one particular fuel assembly or a group of assemblies which must neither be loaded nor transported for reprocessing or cask licensing reasons.
- The transporter (COGEMA-STS or NTL), which prepares the loading plans in accordance with the contractual documentation passed on by the reprocessor (i.e. lists of fuel assemblies and the corresponding reservations) and the position of each fuel assembly in the storage pond given by the reactors. The transporter is also responsible for the fuel identification at reactor sites and guarantees the conformance of the loading with the pre-established and approved loading plans.

As a starting point, we highlighted two major paths, that we conservatively considered as independent, which could lead to a misloading:
- An error during the preparation of the loading documentation at the office site;
- An error during the loading of the transport cask at the reactor site.



We then developed the conditions of occurrence of these "macro-events" by carrying out a thorough task analysis based on the application of the procedures used by the operators, at the office for the preparation of the loading documentation and at the reactor sites for the cask loadings. The implementation of a comprehensive quality assurance system at COGEMA and NTL enabled us to cover the whole fuel identification process through written procedures and formal records.

From each procedure, we carried out a failure mode analysis and defined the basic events which combined in the fault tree representation lead to the transport of a non-approved fuel assembly. Probabilities were defined from the task analysis and assigned to each basic event. The probability to transport a non-approved fuel assembly was then calculated.



TASK ANALYSIS

The first step in task analysis is data collection. In order to gather the necessary background information about the system's context and task requirements, we collected all the procedures involved in the fuel identification process. Data collection was also completed by staff interviews and inspections at reactor sites. Owing to space limitation and commercial confidentiality, it is not possible to fully describe the fuel identification procedures in this paper. However a brief description of the procedure used by NTL at reactor site is given as an example in appendix 1.

The process of fuel identification for cask loading consists solely of a succession of human actions such as reading, writing, comparison of a set of digits etc...Therefore, only a human error in performing an action can lead to the failure of the task. Task analysis aims at identifying the Performance Shaping Factors (Swain and Guttmann 1983) which can affect the human performance in the accomplishment of a procedure or of a given task. Again, it is not possible to present in this paper the full task analysis, but we will summarize its main steps and findings.

Environmental characteristics

We have here to make the distinction between the office environment where loading plans are prepared and the fuel storage pond in the controlled area of the reactor where fuel assemblies are identified and loaded into the transport cask. There is little to say about the office environment as it can be described as optimal for the preparation of the loading documentation. Transport of spent fuel is a long term planned activity and there is no hurry as lists of fuel assemblies and their pond positions are received and checked a long time in advance, allowing enough response time for decision-taking. Normal working time and factors such as noise, space, general comfort are kept to an optimum.

By comparison, the controlled area environment is not so comfortable for the operators in charge of fuel identification. Because of factors such as wearing protective overall, gloves etc... and stress due to possible exposure to contamination and radiation, it is recognised that working in a controlled area affects the human performance. Several factors can affect the fuel identification at reactor sites:

- The spotting of the (X,Y) coordinates of the matrix which defines the storage pond (are the coordinates reported on the fuel rack or simply on the walls of the building?)
- The position of the fuel assemblies to be loaded in the pond (are they in pre-determined positions or spread anywhere in the pond?)
- The optical device used to read the identification numbers under water (is it binoculars or a video camera?)
- The lighting conditions of the pond (are additional floodlights available?)
- The limpidity of the water.
- The number of digits of the identification number (from 3 to 9).
- The number of fuel assemblies to be identified (from 3 to 32).
- The quality of the engraving of the identification numbers.
- The quality of the control documents (are the loading plans legible?)
- The ergonomy of the fuel crane bridge where the operator must stay during the fuel identification.

Working instructions

All the tasks are described in a set of operating procedures prepared by qualified staff. These procedures are usually short (less than ten actions) and are carefully verified before being distributed to all people having an activity to perform in the process. They are also completed by written quality plans or check-lists which constitute the records. Loading plans are reviewed for adequacy and readability before utilization. Due to the poor quality, facsimile transmission of information is avoided.

Audits

Internal and external audits are carried out on a regular basis in order to verify the application of the operating procedures. Non-conformances are formaly raised and corrective actions implemented.

Staff and training

Staff assigned to loading plan preparation, and to fuel identification at reactor sites, are trained and qualified.

Working hours

On some reactors normal working time does not allow to complete the cask loading and despatch within one week, and a change of the work team is thus necessary. This may arise during fuel identification.

Perceptual requirements

The main perceptual requirement when identifying fuel assemblies at reactor site is eyesight. This is important during the reading operation, where fuel identification numbers are not easily legible, as well as when the identified fuel assembly is taken from its pond position and transferred into the cask.

Interpretation and decision making

Interpretation and decision making occur during the reading and the comparison steps. The operator has to decide to stop the loading operations in case of discrepancy between the identification number read and the one shown on the loading plan. Two decisions are possible: stop or continue. In this study, a decision to stop the loading operations has been considered as always adequate. In bad identification conditions, a doubt can arise on the fuel assembly number read by the operator. For instance, one may take a B for a 8 or a G for a C. An operator already knowing the identification number can be biased and tempted to recognize on the fuel assembly, the number which is on the loading plan. This has been minimized by adopting a "blind" identification procedure in which the right number is only accessible to the operator after having read and noted the number seen in the pond.

Human redundancy and dependence level

Loading plans are internally verified according to a written procedure and endorsed by the reactors.Fuel identification is also cross-checked by the reactor staff. During the verification operations dependence level is kept as low as possible.

Language

It may happen on some European reactors that the native language of the operator in charge of fuel identification is not that of the reactor staff. However, we always ensure that a common language exists between the reactor staff and the operator.

Time constraint

The loading of a spent fuel cask is a planned activity which takes about one full week. An interruption during the fuel loading in order to solve an identification problem may delay the shipment and disrupt the transport programme. Therefore, an operator might be tempted to endorse a would-be minor non-conformance and carry on with fuel loading to respect the transport programme.

BASIC EVENTS PROBABILITIES

Having carried out the task analysis and thus identified the performance shaping factors, we were faced with the difficult problem of assigning probabilities to each basic event. Our internal database, based on operational experience and a review of previous non-conformances enabled us to derive some of the necessary probabilities. For example, and according to our statistics, the probability that a given fuel assembly is not at the position in the pond storage rack declared by the reactor, is ranging from 1E-3 to 5 E-3.
Other probabilities were derived from existing litterature (Swain and Guttmann 1983) when applicable (e.g. assimilation of fuel identification numbers to digital displays) or from generation techniques (Kirwan et al. 1990)(Williams,1988). Individual basic event probabilities were validated when we compared the results given with these input data to the measured failure rate.

CALCULATIONS AND RESULTS

In our fuel identification process, a part of the procedure represents a non-coherent system with independent basic events in which two successive failures might result in a success. Although these scenarios are very unlikely, they were taken into account and the modelization of this part was developed by the CEA-SERMA laboratory using the maximal cut technique (Eid et al. 1990). The rest of the system was calculated using normal fault tree analysis. This study gave the following results per fuel assembly:

Procedure used on French Electricité de France power plants

- Probability that a loading plan comprises a non-approved fuel assembly (i.e. with a coherent fuel identification number and pond position):
From 1.1 E-7 to 6 E-7
- Probability to load a non-approved fuel assembly at a reactor site having a correct loading plan:
From 2.2 E-7 to 5.5 E-6

- Overall probability to transport a non-approved fuel assembly:

From 3.3 E-7 to 6.1 E-6

Assuming a flux of 1660 fuel assemblies loaded per year, hence a mean time between failure comprised between 99 years and 1825 years.

Procedure used on other European power plants

- Probability that a loading plan comprises a non-approved fuel assembly (i.e. with a coherent fuel identification number and pond position):

From 5.5 E-9 to 1.1 E-7

- Probability to load a non-approved fuel assembly at a reactor site having a correct loading plan:

From 8 E-7 to 6 E-6

- Overall probability to transport a non-approved fuel assembly:

From 8.055 E-7 to 6.11E-6

Assuming a flux of 1940 fuel assemblies loaded per year, hence a mean time between failure comprised between 84.4 years and 640 years.

Assuming a pessimistic probability of 5 E-3 fresh fuel assembly remaining accessible in the storage pond (these fuel assemblies are usually stored in a separate dry and locked rack), we calculated the probability to load a non-irradiated and non-approved fuel assembly:

From 5 E-9 to 1.5 E-8

The final step being the probability to transport a non-irradiated and non-approved fuel assembly after re-identification before closing the cask :

From 4 E-11 to 3 E-10

The latter two results fell into what is considered as acceptable.

DISCUSSION

Although in the analysis of the problem and during its mathematical modelization we applied ourselves to abide by the actions really performed, some aspects may not have been taken into account. Especially during the failure mode analysis of each human action, some modes may have escaped our attention or were deliberately omitted as they were estimated to be highly unlikely. When we determined the basic events, we came up against the problem of quantifying the ranges of failure rates. Indeed, we do not have a database rich enough to provide all the required human failure probabilities. We had to use existing litterature when applicable, generation techniques or expert judgement if there was a total lack of data. Furthermore, we have minimized the human redundancy when checking was not formalized by written records. We have also ignored that COGEMA-STS and NTL use a common fuel element data base for loading plan preparation on which fuel element data are only available after formal approval. All these conservative assumptions led us to an over-estimation of the human failure rates and consequently to a pessimistic overall probability of transporting a non-approved fuel assembly.

In order to validate our basic assumptions, it is interesting to compare the calculated probability resulting from the theoritical modelization to the measured failure rate resulting from our experience as consignors. Since the implementation of the current fuel identification procedures in February 1984, NTL have transported more than 10,000 fuel asemblies to the COGEMA reprocessing plant at La Hague without any mistake on fuel identification, giving the system a measured failure rate better than 1 E-4 . However, since that date, no loading was stopped due to an identification mistake detected during the second fuel identification before closing the transport cask, and the 1 E-4 probability must therefore be compared with the one resulting from an intermediate calculation:"Probability of loading a non-approved fuel assembly before re-identification" which lay between 1E-4 and 3 E-4. This comparison confirms the conservatism of our basic events probabilities.

IMPROVEMENT TO THE FUEL IDENTIFICATION PROCESS

The study of the most likely failure scenarios and task analysis enabled us to improve our identification procedures and thus to increase the overall reliability. The first idea which comes for improving the human performance is redundancy. However, all the actions concerning our procedures being already cross-checked, we preferred not to introduce a second level of human redundancy. As well as being costly, this would have been difficult to implement due to the dependence between people implied and the doubtful efficiency. Instead of altering the existing list of actions, we focused on the prevention of a misloading and the possibility of recovering errors before shipment by the following actions:

- Generalization of the pre-loading positions. The fuel assemblies selected for a given transport are set apart from the bulk of the stored fuel. 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 transports of the campaign. This also provide a preliminary fuel identification by the reactor staff.
- Training the staff in charge of the fuel identification with emphasis on the key points of the procedures. Each new operator is sent several times for training at reactor sites with experienced staff in order to get a full knowledge of the particularity of the environment on each reactor.
- Limitation of the deviations from the procedures by a regular control of their application through internal audits both at the office and at reactor sites.
- To keep the dependence level between operators and checkers as low as possible.
- Written records of the checkings carried out on each action.
- Heightening of the reactor fuel handling staff awareness to fuel identification prior to transport.

CONCLUSION

This study has been carried out to demonstrate the reliability of the system of the spent fuel identification used by COGEMA and NTL prior to shipment to the reprocessing plant of La Hague. This was a prerequisite for the French competent authority to accept the "burnup credit" assumption in the criticality assessment of spent fuel packages. The probability to load a non-irradiated and non-specified fuel assembly was considered as acceptable if our identification and irradiation status measurement procedures were used. Furthermore, the task analysis enabled us to improve the working conditions at reactor sites, the quality of the working documentation, and consequently to improve the reliability of the system. The NTL experience of transporting to La Hague, as consignor, more than 10,000 fuel assemblies since the date of implementation of our system in 1984 without any non-conformance on fuel identification, validated the formalism of this study as well as our assumptions on basic events probabilities.

REFERENCES

M.Eid, M.Zachar, P.Prétesacque, "Reliability of the Spent Fuel Identification for Flask Loading Procedure Used by COGEMA fo Fuel Transport to La Hague", Proceedings from the 11th Advances in Reliability Technology Symposium, Liverpool, April 1990, Elsevier.

B.Kirwan, B.Martin, H.Rycraft and A.Smith "Human Error Data Collection and Data Generation",Proceedings from the 11th Advances in Reliability Technology Symposium, Liverpool, April 1990, Elsevier.

P. Prétesacque, F. Corny "Spent Fuel Acceptance for Transport and Reprocessing", Proceedings PATRAM '89 CONF-890631-vol.3 June 11-16,1989 Washington DC.

T.L. Sanders, W.H. Lake "Alternatives for Implementing Burnup Credit in the Design and Operation of Spent Fuel Transport Casks", Proceedings PATRAM '89 CONF-890631-vol.2 June 11-16,1989 Washington DC.

A.D. Swain and H.E. Guttmann "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications" U.S. Nuclear Regulatory Commission, NUREG/CR-1228-F August 1983.

J.C. Williams,"A Data-based Method for Assessing and Reducing Human Error to Improve Operational Performance" IEEE 4th Conference on Human Factors and Power Plants 5-9 June 1988 Monterey, California.

TN 13/2 Package approval F/274/B(U) F-85 Ca, 1991.

IAEA "Regulations for the Safe Transport of Radioactive Material", Vienna, 1985 Edition.

APPENDIX 1

1. Read on the loading plan, the (X,Y) coordinates of the first fuel assembly;

2. Read the identification number of the fuel assembly found in the (X,Y) position;

3. Write this number on the loading plan;

4. Remove the masking sticker which hides the identification number of the assembly to be loaded and compare both numbers.

5. If both numbers correspond, grasp the fuel assembly ensuring it is taken from its correct pond position;

6. If required check the irradiation status of the fuel assembly;

7. If the irradiation criteria is reached, then load the fuel assembly into the cask and sign the loading plan;

8. Repeat operations 1 to 7 according to the loading plan;

9. Re-identify the first fuel assembly and write the number on the loading plan;

10. Compare the number read with the loading plan and sign it;

11. Repeat operations 9 to 10 according to the loading plan;

12. Close the cask.

If a descrepancy occurs during comparison operations then <u>stop the loading operations</u> and contact the NTL office.

All operations are cross-checked by the reactor fuel handling staff.