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CLEANING AND DISMANTLING OF HOT CELLS DEDICATED TO MECHANICAL TREATMENT AND SHEARING OF SPENT FUEL – CRITICALITY SAFETY ISSUES

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ABSTRACT

The Marcoule Pilot Plant (“Atelier Pilote de Marcoule” - APM) was a semi-industrial facility dedicated to the reprocessing of spent fuel. It was used to validate the reprocessing flowsheets for natural uranium fuels, then fast neutron reactor fuels and light water reactor fuels. Since 1997, operation has been stopped and the plant is being cleaned up and dismantled. APM includes three nuclear buildings (211, 213, and 214). Building 214, operated from 1988 to 1997, was used for the storage, mechanical treatment and dissolution of spent fuel, as well as clarification of dissolution solutions. This building includes cells 418 and 421, which are dry “hot cells” (high dose level), where fuel cases were opened and fuel pins were sheared. The remaining fissile materials in these cells are mostly powders accumulated during operation, mainly in Cell 418.

The preparatory operations for dismantling can be divided into two main steps:

- *First, equipment cleaning and disassembly were carried out, with no significant modification of the criticality safety case,*
- *Then, dismantling operations, with the cutting of process equipment and wet cleaning were initiated. These operations required the development of a new criticality safety case.*

The aim of this paper is to present the issues associated with the new criticality safety case with regard to this second step, including:

- *The evaluation of the masses of fissile material initially remaining in the cells, and removed in the waste produced during dismantling,*
- *The choice of criticality control modes, taking into account the progress of the operations: limitation of mass and moderation, then limitation of the mass only (no moderation limit),*
- *The choice of the fissile reference medium, which required a specific justification given the various types of fuels that have successively been treated in the cells,*
- *The criticality calculations carried out and the criticality safety case, which includes a follow-up of the recovered masses of fissile material, with associated limits and hold points.*

In addition concerning criticality safety, feedback from the dismantling operations carried out to date will be presented. In particular, the evaluation of the masses of fissile material actually recovered will be compared with the limits associated with hold points, and with the maximum permissible limits for subcriticality.

KEY WORDS

Criticality, Dismantling, APM.

1. INTRODUCTION

The cells 418 and 421 are part of the Marcoule Pilot Plant (“Atelier Pilote de Marcoule”- APM). They are located in Building 214, which was built during the 1980s and operated from 1988 to 1997. Both are dry cells, where fuel cases were opened and fuel pins were sheared. The remaining fissile materials in these cells are mostly powders accumulated during operation. The dismantling operations, including the cutting of

process equipment and wet cleaning, have required the development of a new criticality safety case. This paper presents the principles and issues associated with this new safety case, and the feedback from dismantling operation carried out to date.

2. APM FACILITY

The Marcoule Pilot Plant (“Atelier Pilote de Marcoule” - APM) was a semi-industrial facility dedicated to the reprocessing of spent fuel. APM was hot-commissioned in 1962 as a pilot-scale unit designed to validate the operation of spent-fuel reprocessing flowsheets developed in laboratories [1]. It included more than twenty cells for fuel reprocessing and R&D programs.

APM was first intended to design and develop methods for reprocessing natural uranium graphite gas (NUGG) reactor fuels, but was then operated for several campaigns on oxide fuels separated by periods during which existing equipment was modified or new equipment was installed.



Figure 1. General view of APM

The key dates for reprocessing operations at APM are:

- Hot commissioning (Building 211): 1962
- Reprocessing of NUGG fuel (Building 211): 1962-1967
- Modification for reprocessing of oxide fuel: 1967-1973
- Reprocessing of fast neutron reactor (FNR) oxide fuel (Building 211 -“TOP” line): 1974-1983
- Extension and modification of the facility – Construction of Building 214: 1983-1988
- Reprocessing of FNR oxide fuel and R&D for PWR fuel (Buildings 214 + 211 -“TOR” line): 1988-1994
- Start-up of APM-UP1 connection: 1994
- Dissolution of oxide and undedicated fuel in Building 214 and transfer of solutions to UP1: 1994-1997.

APM includes three nuclear buildings (Figure 2):

- Building 211 was operated from 1962 to 1994 to extract and purify uranium and plutonium, and to concentrate the fission product solutions; the building also includes analysis and R&D laboratories,
- Building 214, operated from 1988 to 1997, was used for the receipt, storage, mechanical treatment, and dissolution of spent fuel, as well as the clarification of dissolution solutions,
- Building 213, hot-commissioned in 1969, stores blocks of fission products which were vitrified in the R&D units.

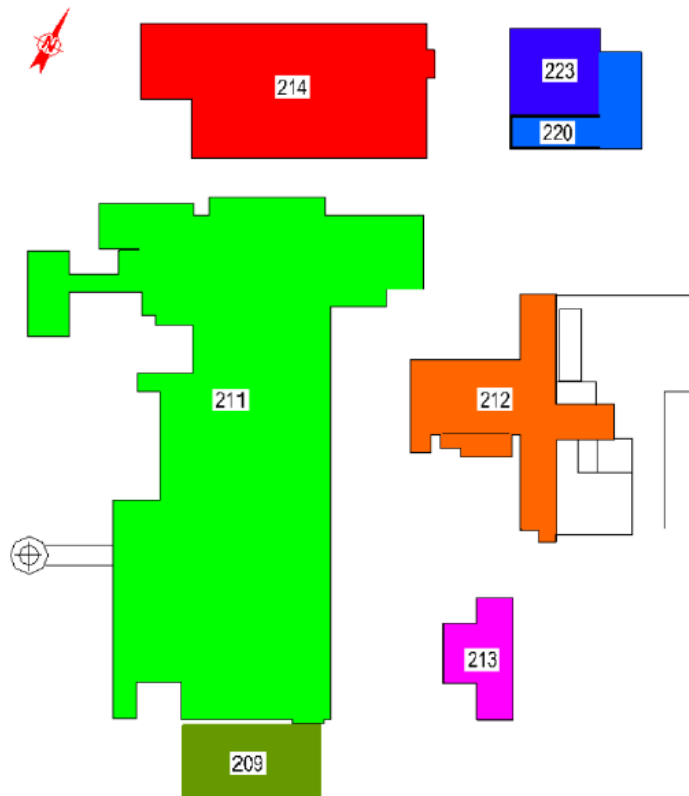


Figure 2. APM Buildings

The end of reprocessing activities at APM occurred in three steps:

- 1983: “TOP” line (Building 211),
- 1994: “TOR” solvent-extraction line (Building 211),
- 1997: “TOR” dissolution line (Building 214).

The last step (1997) was linked to the final shutdown of the UP1 reprocessing plant [2], as since 1994, clarified dissolution solutions had been transferred from APM to UP1.

3. THE HOT CELLS 418 AND 421

The cells 418 and 421, located in building 214, are dry “hot cells” (high dose level) where the opening of the fuel cases and the shearing of the fuel pins were performed.

The structure of these two hot cells is presented in Figure 3.

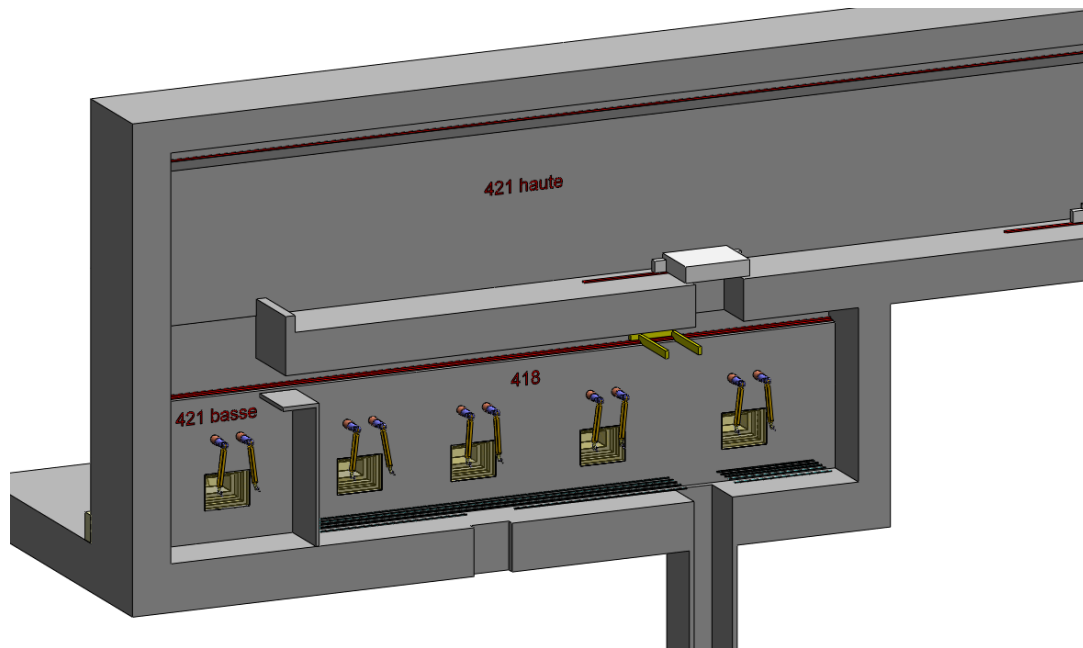


Figure 3. Hot Cells 418 and 421

Hot cell 421 is divided into two parts:

- the upper part (“421 haute”) which is an intervention corridor with no fissile material,
- the lower part (“421 basse”) where the mechanical pre-treatment of the irradiated fuel was performed: arrival of a fuel case from storage, opening of the case, extraction of the fuel pins, sorting and transfer of the pins to Cell 418.

The mechanical treatment performed in Cell 418 consisted in the following operations:

- removing the spacer wire and cutting of the upper and lower parts of the fuel pins,
- shearing of fuel pins into the dissolution basket.

Cells 421 and 418 are connected to each other by a channel which enabled the transfer of the pins one by one. In addition, a transfer air lock called "sas Fortissimo" gave another connection between the two cells.

Both cells contain many mechanical treatment or handling pieces of equipment (such as shears, conveyors, remote manipulators, etc. ...).



Figure 4. View of Hot Cells 418 and 421 (initial situation)

During normal operation, the criticality safety in Cells 421 and 418 was mainly based on the limitation of the number of pins and the absence of moderation. The maximum number of pins in the cells was low compared to the minimum critical number of clad pins in air (with no moderation).

The accumulation of oxide powders due to shearing was not considered to be significant, because of the regular cleaning performed with a safe geometry vacuum cleaner.

The storage of dissolution baskets was a specific case, as its criticality control mode was the limitation of geometry.

4. THE PREPARATORY OPERATIONS FOR DISMANTLING

The preparatory operations for dismantling can be divided into two main successive steps:

- Cleaning and disassembly of equipment,
- Dismantling operations, process equipment cutting, and wet cleaning.

a. Cleaning and disassembly of equipment

These operations were very similar to those performed in normal operation for the replacement of pieces of equipment or the cleaning of the cells:

- Treatment of removable parts,
- Dry cleaning of the cell by sweeping and/or vacuum cleaning,
- Tele-operated disassembly (without cutting).

These operations did not lead to a significant modification of the criticality safety case, as:

- The introduction of hydrogenated fluids or materials into the cells remained prohibited,
- The vacuum cleaning of powders or dust was carried out under the same conditions as in normal operation (use of the same “safe by design” vacuum cleaner),
- Waste management followed already existing facility rules.

b. Dismantling operations, process equipment cutting, and wet cleaning

These operations included significant changes:

- Cutting of pieces of equipment,
- Cutting, cleaning, and conditioning of the least irradiating waste in the upper part of Cell 421,
- Wet cleaning in the cells (use of hydrogenated fluids).

For this second step, the development of a new criticality safety case was thus required. This new safety case is presented in the next section.

5. CRITICALITY SAFETY CASE

a. Initial conditions of the cells

Considering its functionalities (shearing of fuel pins), Cell 418 was the one most likely to contain the majority of fissile material. However, during normal operation and during the first step of cleaning and disassembly of equipment (see § 4 a), cleanings had been carried out. The amount of fissile material is considered residual, mainly in the form of dispersed powder near the shearing zones and the spacer wire removal zone. Shearing blocks may also contain potential retention zones.

A very penalizing and unrealistic estimate of the residual mass (assuming all shearing blocks filled with oxide of maximum density) leads to a maximum mass of 15 kg of heavy metal. The best estimate of probable residual mass is nevertheless much lower.

Residual amounts of hydrogenated fluids (in closed capacities, mainly in oil pans) are as follows:

- 10 kg total in Cell 421, including 3.5 kg in the biggest single capacity,
- 6 kg total in Cell 418, including 1.1 kg in the biggest single capacity.

b. Criticality control modes

The dismantling operations, process equipment cutting, and wet cleaning (as defined above in 4 b) have been divided into two different steps with different criticality control modes:

- for phase 1, the control mode is the limitation of mass and moderation,
- for phase 2 (including wet cleaning), the control mode is the limitation of mass.

c. Reference fissile medium

The choice of the reference fissile medium was not such an easy concern, as various types of nuclear fuels were processed in APM Building 214. These fuels can be divided into different types:

- FNR and MOX fuels: These fuels are mixed oxide fuels with the following penalizing characteristics for criticality safety: Natural Uranium; $\text{Pu} / (\text{U} + \text{Pu}) < 28 \%$; $^{240}\text{Pu} / \text{Pu}_{\text{total}} > 15\%$.
- Highly Enriched Uranium (HEU) oxide fuels: These fuels, coming from research reactors, are more penalizing (for criticality safety) than the FNR and MOX fuels. However, it can be noted that:
 - These fuels represent a very small percentage of the mass of fuel which was processed in the facility,
 - Some specific tests were performed during the processing of these fuels in order to check that they had not led to a significant accumulation of fissile material,
 - After the processing of these fuels, large quantities of low enriched fuels were processed in the cells.

Considering the points above, it was considered admissible not to take these HEU fuels into account for the definition of the reference fissile medium.

- Low Enriched Uranium (LEU) oxide fuels and FNR blankets: Given their low content of fissile material, it can be demonstrated that these fuels are less penalizing than the worst-case FNR/MOX fuel mentioned above.

In conclusion, the reference fissile medium chosen was MOX ($\text{UO}_2\text{-PuO}_2$, with Natural Uranium, $\text{Pu} / (\text{U} + \text{Pu}) < 28 \%$; $^{240}\text{Pu} / \text{Pu}_{\text{total}} > 15\%$), moderated by water.

d. Criticality safety case: Phase 1

For phase 1, with a mass + moderation control mode, some existing calculations were used with the following model (heterogeneous moderation), with a fixed volume of water and a fixed total mass of fissile material:

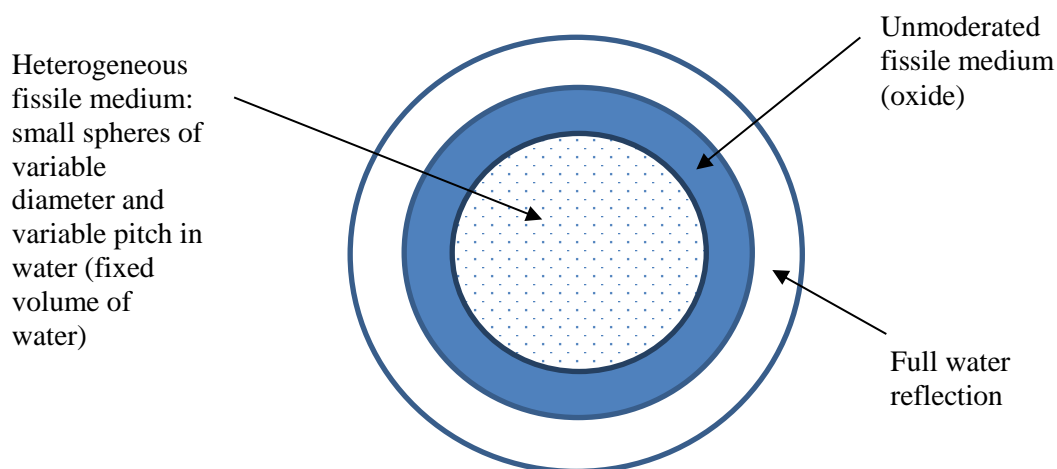


Figure 4. Calculation model for phase 1

Due to the lack of representative benchmarks with unmoderated MOX fuel, a bias of 2000 pcm was retained. The criticality safety criteria were then $K_{\text{eff}} + 3\sigma \leq 0.93$ in normal operation and $K_{\text{eff}} + 3\sigma \leq 0.95$ in abnormal conditions (leakage, human error, etc...).

The selected couple (Mass of fissile material (U + Pu) / Volume of water) was 25 kg/ 7 L, giving a maximum value for $K_{\text{eff}} + 3\sigma$ of 0.955. This was considered acceptable in abnormal conditions, considering the safety margins due to the very penalizing model.

These calculation results also allowed justification of criticality safety in normal operation because:

- in normal operation, it has been considered that the closed capacities of oil (see § 5.a) could not moderate fissile material, so the maximum volume of moderator is only 2.5 L (decontamination liquids and wipes),
- the remaining mass of fissile material in Cells 418 + 421, even estimated with a penalizing approach, is much lower than 25 kg, and a stop point is planned if 10% of that limit is reached (see below).

A management of hydrogenated materials has been implemented, with a maximum permitted limit of 2.5 L in Cells 418 + 421. The quantities of hydrogenated products (decontamination liquids and wipes) are limited to the equivalent of 2.5 L of water. For this, only one bottle of liquid and a limited quantity of wipes are allowed. Before renewing the bottle or the wipes, it has to be checked that hydrogenated products have been removed from the cells.

In abnormal conditions the maximum equivalent volume of water would be 7 L, corresponding to the sum of:

- 2.5 L already authorized in normal operation,
- 1 L considered introduced by mistake,
- 3.5 L due to the possible leakage of the biggest single capacity of oil (the leakage and moderation of fissile material by two or more capacities in the same time has not been considered as credible).

The introduction of the equivalent of 1 L of water due to a single mistake was considered a pessimistic hypothesis taking into account the operating mode of introduction, which includes a double monitoring and a technical limitation of any single entry of hydrogenated products (only moistened wipes).

Considering the mass limit of 25 kg of U+ Pu, even if it appears to be much higher than any credible remaining mass in the two cells, it was decided to monitor the total mass of fissile material removed from the cells during the dismantling.

The mass of fissile material is first pre-evaluated in the cell itself by a dose rate measurement (associated to a spectrum and a transfer function) then a gamma-neutron measurement is performed in another Cell (409), dedicated to waste treatment.

A conservative breakpoint limit is defined: if the total cumulated mass reaches 2.5 kg, which is 10% of the subcritical limit of 25 kg, the operations are stopped, and can only restart on specific authorization by the facility manager, after agreement by the criticality safety specialists.

e. Criticality safety case: Phase 2

For phase 2, which includes wet cleaning, the criticality control mode is the limitation of mass only (optimal moderation).

The mass limit for the reference fissile medium (as presented in § 5 c) was defined using existing standard calculations whose main results are presented in Table I. The safe values were deduced from the critical values by applying a standard safety coefficient [3].

Table I. Critical parameters for the reference fissile medium at optimal moderation with full water reflection (20 cm)

Heterogeneous MOX, UO ₂ -PuO ₂	Mass (U+Pu)	Spherical volume	Cylinder diameter
Critical value	3.1 kg	13.6 L	19.6 cm
Safe limit	2.17 kg	10.2 L	16.7 cm

The safe mass limit of 2.17 kg of U+Pu has to be guaranteed before the beginning of Phase 2.

This means a reliable evaluation of the remaining mass of fissile material must first be obtained. It is therefore necessary before the beginning of phase 2:

- to guarantee that there are no remaining unchecked retentions,
- to ensure that all the containers of powders or waste have been removed,
- to estimate the remaining mass of fissile material in the cells.

Concerning the progress of operations in phase 2, a conservative breakpoint limit was also defined: if the total cumulated mass reaches 1.5 kg, which is 70% of the safe limit of 2.17 kg, the operations are stopped, and can only restart on a specific authorization by the facility manager, after agreement by the criticality safety specialists.

6. FEEDBACK FROM THE FIRST DISMANTLING OPERATIONS

The dismantling operations are currently running in Cells 418 and 421. The cleaning and disassembly of equipment (as described in § 4 a) has been completed, and phase 1 (as described in § 4 b and § 5 d) of the dismantling operations and process equipment cutting is still under way. Phase 2 (as described in § 4 b and § 5 e) has not started yet.

In May 2019, 11000 kg of equipment had been processed, compared to a total of 15000 kg initially present in the two cells.

The masses of fissile material actually recovered are very limited and confirm the pessimism of the criticality safety case:

- during the first step of cleaning and disassembly of equipment, the total mass of fissile material removed in waste or transferred into specific containers was less than a hundred grams,
- during the second step of dismantling operations and process equipment cutting, the total recovered mass of fissile material removed in waste or transferred into specific containers is currently less than two hundred grams.

These masses are very low compared to the subcritical limits and even to the breakpoint limits presented in § 5. However, it should be noted that the shearing blocks, which might contain the highest masses of fissile material, have not been processed yet.

7. CONCLUSIONS

To summarize, this paper has presented the special features of a criticality safety case concerning the dismantling of two dry hot cells, used for the mechanical treatment and shearing of spent fuels in a reprocessing plant. The definition of the reference fissile medium had to take into account the reprocessing history of the cells, i.e. the various types of fuels involved. The definition of the criticality control modes (mass + moderation, then mass only) had to take into account the progress of the operations. The comparison of the masses actually recovered with the subcritical limits and breakpoint limits cannot be completed yet, as the operations are still running, but to date the initial hypothesis of the criticality safety case appears to have been pessimistic.

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