



HAL
open science

Characterization and evacuation of historical irradiated fuels

Clément Lopez, Fleur Lespinasse, Maxime Wijayalath, Vincent Roux

► **To cite this version:**

Clément Lopez, Fleur Lespinasse, Maxime Wijayalath, Vincent Roux. Characterization and evacuation of historical irradiated fuels. NCS2022, ANS, Jun 2022, Anaheim, United States. cea-04169869

HAL Id: cea-04169869

<https://cea.hal.science/cea-04169869v1>

Submitted on 24 Jul 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Characterization and evacuation of historical irradiated fuels

Clement LOPEZ, Fleur LESPINASSE, Maxime WIJAYALATH, Vincent ROUX

French Alternative Energies and Atomic Energy Commission (CEA)

CEA Paris-Saclay, Gif-sur-Yvette, France

clement.lopez@cea.fr

[Digital Object Identifier (DOI) placeholder – to be added by ANS during production]

ABSTRACT

This paper presents the summary of the nuclear criticality safety assessment related to the characterization and evacuation of historical cases containing irradiated fuels. These fuels have been stored for several decades (first fuel elements were stored in 1961) in two blocks (named 116 and 108) located in the nuclear facility intended for solid waste management at the CEA Paris-Saclay center (nuclear facility n°72).

These blocks are concrete blocks pierced on either side by horizontal tubular channels. The total storage capacity is about 700 cases distributed in more than seventy channels.

The fissile materials stored are in different forms (sections, pellets, powder, etc.) with various characteristics (oxide, metal, etc.) and isotopies. Their maximum enrichment in ^{235}U is 12%. Some cases contain MOX fuels.

In order to confirm or to know better their characteristics, a dedicated cell is used to assess the fuels. For this purpose, a shuttle transfers the cases then stores them again in the blocks for evacuation.

In 2021, the block 116 is empty of fuels. The block 108 contains about thirty cases initially present, including the channels containing the Pu-Rapsodie fuels, which will be evacuated in 2022.

This paper presents the method used to demonstrate the nuclear criticality safety of all the operations. It presents the calculations results associated with the operations and equipments used. In addition, from the point of view of nuclear criticality safety, it also presents the experience feedback and the operational highlights.

Key Words: Irradiated fuels, historical, characterization, evacuation

1 INTRODUCTION

Two concrete blocks are located in the nuclear facility intended for solid waste management at the CEA Paris-Saclay center (nuclear facility n°72): one called "108" located in building 108 and the other called "116" located in the hall of building 116. These blocks contained, in particular, cases containing irradiated fuel, some of which had been stored for more than fifty years.

In preparation for their disposal, a large proportion of these fuels were examined in a shielded cell.

Historically, the block 108 contained more than 600 cases (including about twenty "Pu-Rapsody" cases) distributed in about sixty channels. The block 116 contained about sixty cases containing fuel elements distributed in about ten channels.

The project was carried out in several phases. The first two phases were completed at the end of 1998. They enabled the majority of the cases in the blocks to be assessed, a large proportion of which were

evacuated. The third phase of the project started in 2003 in order to assess the last cases whose characteristics were partially known.

In parallel to this third phase, the project continued to evacuate the cases assessed in the previous phases.

In 2021, the block 116 is empty of fuels. The block 108 contains about thirty cases initially present, including the channels containing the Pu-Rapsodie cases, which will be evacuated in 2022.

2 CHARACTERISTICS OF FISSILE MATERIAL

The fissile materials stored are in different forms (sections, pellets, powder, etc.) with various characteristics (oxide, metal, etc.) and isotopies.

The characteristics of fissile materials were investigated in the archives by the CEA.

The fuels are the result of experiments and mostly come from the Laboratory for Studies on Irradiated Fuels (LECI). They mainly contain pieces of fuel from experiments conducted by the CEA in the EL2 and EL3 reactors (at Saclay) during the 1950s and 1960s.

For example, the Pu-Rapsodie fuels, stored in block 108 and assessed in a specific file, are the result of experiments on irradiation devices to guide the choice of fuel to be used for the RAPSODIE reactor (sodium-cooled fast neutron reactor located at CEA Cadarache center which diverged in 1967 and closed in 1983).

The fuels are from different sources and have different characteristics (see Table I for block 108).

Table I. Characteristics of fuels stored in the block 108

Type of fuel	²³⁵ U enrichment or Pu content
UOX	12 % in ²³⁵ U max
Pu-Rapsodie	> 90 % in ²³⁵ U max
	(Pu/(U + Pu)) = 50% max

For the block 116, the channels contain pieces of fuel from EL2, EL3 or G1 with the maximum enrichment shown in Table II.

Table II. Characteristics of fuels stored in the block 116

Type of fuel	²³⁵ U enrichment
EL2	0,72 %
EL3 - Metal	1,65 %
EL3 - Oxide	4,5 %
G1	1,35 %

3 DESCRIPTION OF MAIN EQUIPMENTS

3.1 Description of Block 108 and Shuttle 108

The block 108 is a concrete block with 76 tubular channels of 100 mm diameter running through it on both sides. Each channel is closed at both ends by a plug (see Figure 1).

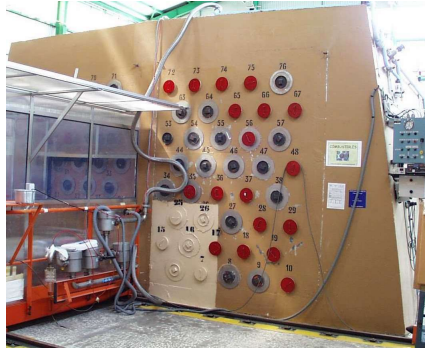


Figure 1: View of block 108 (rear side).

The 108 shuttle has 4 cells of 100 mm diameter and allows the transfer of cases from the block 108 to the shielded cell for expertise or shipping. Its body is covered with 80 mm of lead.

The cases are extracted from the block and placed directly into the shuttle by means of a pusher chain.

3.2 Description of Block 116 and Shuttle 116

The block 116 is a concrete block with 32 tubular channels running through it with diameters (for the channels containing fissile material) of 120 mm and 200 mm. Each channel is closed at both ends by a plug.

The shuttle 116 is a single-cell cylindrical shape with a diameter of 200 mm. Its body is covered with 80 mm of lead.

The movement of the cases in the shuttle 116 is carried out by means of a pusher chain and a shovel, with a diameter adapted according to the case.

3.3 Description of Shielded Cell

The shielded cell is used to assess or evacuate the cases (see Figure 2). The expertise of the cases consists of a weighing and an X-ray to discriminate the contents.



Figure 2: Shielded cell.

4 PROCESS OF OPERATIONS

The sequence of operations is as follows (see Figure 3):

- Transfer of cases from the channel to a shuttle (1),
- Transfer of shuttle to the shielded cell (1),
- Unloading of shuttle in the shielded cell for case expertise (2),
- Transfer of assessed cases by shuttle in block 108 awaiting evacuation (3),
- Evacuation of cases via the shielded cell into a transport package (4).

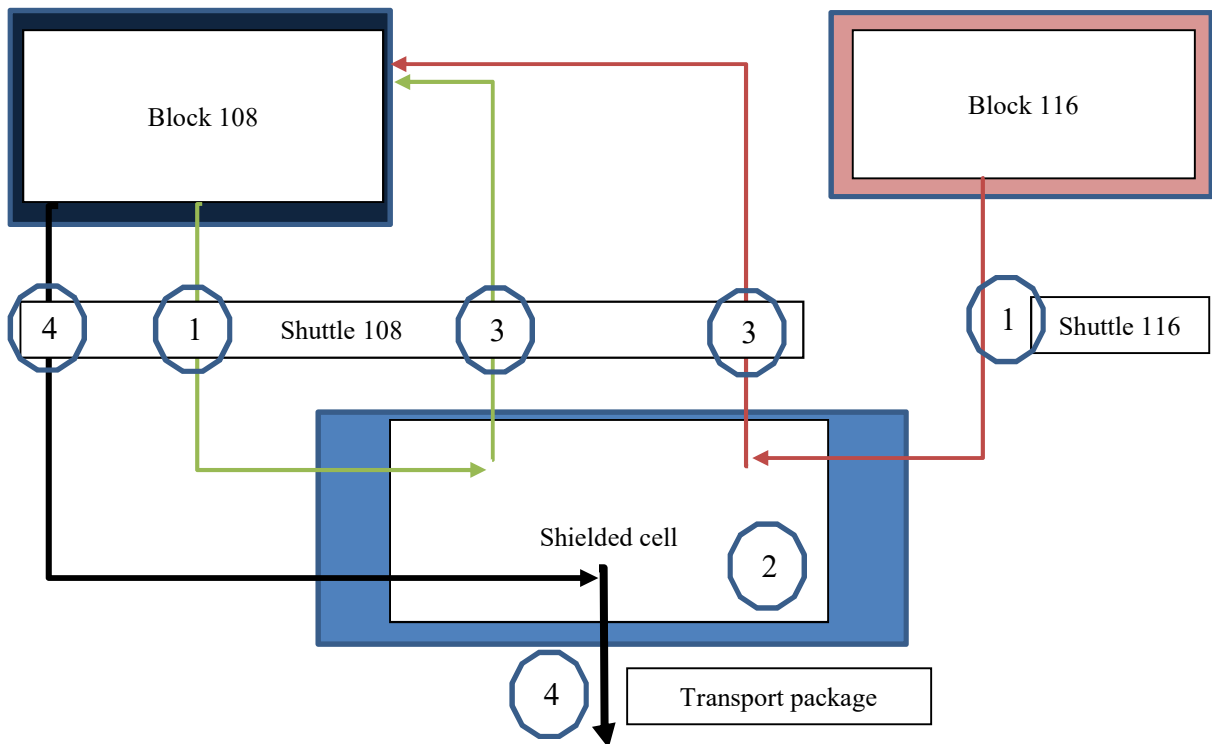


Figure 3: Scheme of operations.

5 NUCLEAR CRITICALITY SAFETY ASSESSMENT

5.1 Conservative Fissile Material

For some equipments, the conservative fissile material is associated with the type of fuel. The conservative fissile material taken into account in the nuclear criticality safety assessment are the following (see Table III):

Table III. Conservative fissile material

Equipment	Conservative fissile material
Block 108	100% $^{239}\text{Pu}_{\text{metal}}\text{-H}_2\text{O}$
Shuttle 108	100% $^{235}\text{U}_{\text{metal}}\text{-H}_2\text{O}$ or 100% $^{239}\text{Pu}_{\text{metal}}\text{-H}_2\text{O}$ (Pu-Rapsodie)
Shielded cell	Heterogeneous $\text{U}_{\text{metal}}\text{-H}_2\text{O}$ with a maximum enrichment of 12% ^{235}U (block 108) or 100% $^{239}\text{Pu}_{\text{metal}}\text{-H}_2\text{O}$ (Pu-Rapsodie) or sintered heterogeneous $\text{UO}_2\text{-H}_2\text{O}$ with a maximum enrichment of 4.5% ^{235}U (block 116)
Block 116	Sintered $\text{UO}_2\text{-H}_2\text{O}$ in heterogeneous form with an enrichment of 4.5 % ^{235}U
Shuttle 116	

5.2 Method of Control

The method of control used during the operations are as follows (see Table IV):

Table IV. Method of control

Location	Equipment	Method of control
Building 108	Block 108	Mass of fissile material and geometrical dimensions
	Shuttle 108	Mass of fissile material and geometrical dimensions
	Shielded cell	Geometrical dimensions (expertise) or mass of fissile material (shipping and Pu-Rapsodie fuels)
Building 116	Block 116	Geometrical dimensions
	Shuttle 116	Geometrical dimensions

5.3 Normal Operating Conditions

5.3.1 Block 108

The nuclear criticality safety of the block 108 has been demonstrated by calculation.

The criticality calculation model used is a network of 80 channels in the form of 8x10x1 cylinders (see Figure 4), with the following assumptions:

- Conservative fissile material with plutonium metal ($^{239}\text{Pu} = 100\%$) homogeneously moderated with water,

- Variable moderation ratio (H/Pu),
- Interstitial moderation of any kind (water of varying density between cylinders),
- Cylinder configuration: 37.2 cm square grid. Each cylinder has a diameter of 10 cm and is filled with the conservative fissile material; the mass of plutonium in each channel is 500 g.

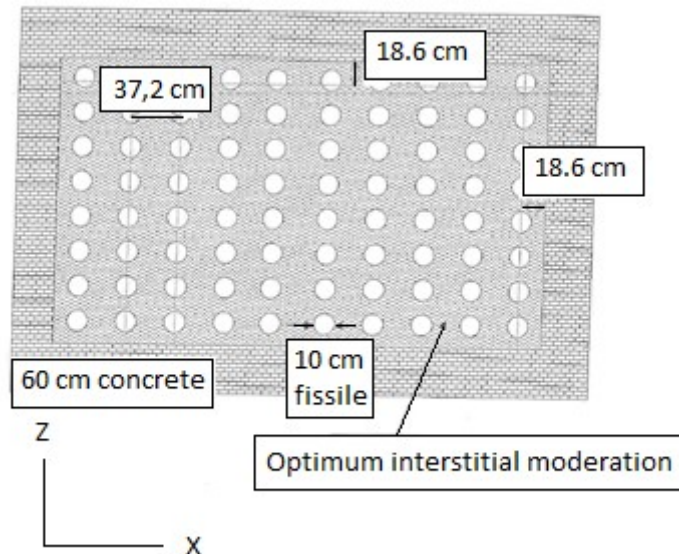


Figure 4: Criticality calculation model of the massif 108

This calculation shows that, under the most conservative conditions, the effective multiplication factor $k_{\text{eff}} + 3\sigma$ is 0.964. This is higher than the upper subcritical limit taken as 0.95 for normal operating conditions.

However, there are many margins associated with this calculation:

- A conservative fissile material with $^{239}\text{Pu} = 100\%$,
- the conservative mesh and pitch of the existing configuration,
- the use of optimum moderation,
- the presence of irradiated fuel in the block,
- A block actually made up of 2 zones of 36 and 40 channels, separated by 75 cm between the 2 channels of the same horizontal line,
- The reduction in the amount of fissile material as the disposal operations proceed.

In view of the margins taken for the criticality calculation model and the actual geometry of the block, the nuclear criticality of the fuels is under control in normal operating conditions.

Block 108 is subcritical with 500 g of fissile material in each of the channels regardless of its moderation.

5.3.2 Shuttle 108

The nuclear criticality safety of shuttle 108 has been demonstrated by calculation with the following assumptions:

- The shuttle:
 - With 4 identical parallel cylindrical steel cells with a thickness of 0.5 cm and an internal diameter of 10 cm, arranged at the top of a square with a diagonal of 20 cm (see Figure 5),
 - All the cells are surrounded by lead with an internal diameter of 35 cm and a thickness of 8 cm, lined with 0.5 cm of steel,
 - Active length of the shuttle: 160 cm,
 - Shuttle closed with a 25 cm thick steel cap,
 - The void between the four cells is modelled by air or water mist of varying density.
- Fissile material: the conservative fissile material is 100% ^{239}Pu (taking into account the Pu-Rapsodie fuels), with a mass limited to 500 g per cell, moderated by water.
- Reflector made of 20 cm water thickness.

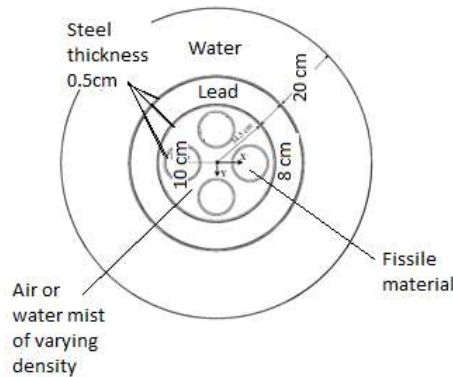


Figure 5. Criticality calculation model of the shuttle 108

Shuttle 108 is subcritical with 500 g of fissile material in each cells regardless of its moderation.

The calculation results show that under these conditions the $k_{\text{eff}} + 3\sigma$ never exceeds 0.90.

5.3.3 Block 116 and shuttle 116

The minimum safe diameter for the conservative fissile material (UO_2 (4.5%) sintered into water in heterogeneous form) is 204 mm.

Channels containing fissile material are therefore geometrically safe (max diameter = 200 mm).

Neutron interactions between channels have not been considered; taking into account the maximum enrichment (concerning only 3% of the cases) gives an additional nuclear criticality safety margin.

The nuclear criticality safety of shuttle 116 was demonstrated by calculation ($k_{\text{eff}} + 3\sigma = 0.879$) taking into account the lead reflection.

5.3.4 Shielded cell

For the expertise operations of the cases from the 108 and 116 blocks (excluding Pu-Rapsodie cases), taking into account a conservative fissile material associated with the type of fuel processed and the shielded cell containing only one case, the cell is subcritical due to the geometry of the case.

For shipping operations, (excluding Pu-Rapsodie cases), in the case of the presence of several cases in the shielded cell, in order to verify the subcriticality taking into account the various enrichments present, it is verified that the sum of the fissile material ratios is less than 1. Thus, for all the cases potentially present at the same time, the following inequality is verified :

$$\sum_i \left(\frac{m_i}{(m_{adm})_i} \right) < 1 \quad (1)$$

Where: $m_i = M_i \times$ multiplication factor and $M_i = (M_e - M_{case})$.

Table V. Parameters taken into account in the sum of the ratios

Size	Unit	Definition
Me	Kg	weighed mass of the case with fuels (the most penalising mass between the archive mass and the weighed mass)
M case	Kg	M case is the mass of the empty case. The mass to be retained depends on the dimensional measurements taken on the case during the examination.
Multiplication factor	Without	factor to be applied according to the chemical form of the fuel (oxide or metal)
(m_{adm})_i	Kg	maximum permissible mass of uranium in the conservative fissile material associated with the contents of the case

For operations associated with Pu-Rapsodie cases with a 100% $^{239}\text{Pu}_{\text{metal}} - \text{H}_2\text{O}$ conservative fissile material, the minimum critical, admissible and safe masses are :

- critical mass = 375 g of ^{239}Pu , reflected by 25 cm Lead + 15 cm H_2O ,
- safe mass (coefficient of 0.7) = 262 g of ^{239}Pu ,
- admissible mass ($k_{\text{eff}} + 3\sigma < 0.97$) = 331 g of ^{239}Pu .

To verify subcriticality, it is verified that in the shielded cell, the mass of fissile material (i.e. the total mass of $^{235}\text{U} + \text{Pu}$) is less than the safe mass of 262 g. In the case of multiple cases in the shielded cell, to verify subcriticality, it is verified that the sum of the fissile masses is also less than 262 g.

When the shielded cell is controlled by a mass limitation (for shipping operations or for Pu-Rapsodie fuels), nuclear criticality safety is achieved by exercising control upstream, from the disposal of cases in the shuttle. For example, for Pu-Rapsodie fuels, the shuttle and the shielded cell are limited to 262 g.

5.3.5 Transport packaging

The nuclear criticality safety of the transport package alone is dealt with in its safety case. Each transport operation must comply with the contents of the transport package safety case.

5.4 Foreseeable Abnormal Conditions

In the nuclear criticality safety assessment, the faults and/or circumstances outside of the normal envelope of operations that may lead to an unsafe situation are:

- The risk of deformation of geometrical dimensions during handling operations,
 - This risk is controlled by operators handling at low speed, limiting maximum lifting heights to a strict minimum and checking handling equipment in accordance with regulations.
- The risk of deformation of geometrical dimensions during a fire,
 - In the case of the shuttle 108, the integrity of the stainless steel walls of the shuttle cannot be guaranteed and the melting of part of the lead can occur. The complete destruction of the 4 full cells, i.e. a maximum of 2 kg of fissile material, does not lead to an unsafe situation.

For a 20% ^{235}U enriched U_{metal} fissile material, with a reflection of 25 cm of lead followed by 15 cm of water, the maximum admissible mass is 3.36 kg, with an upper subcritical limit taken as $k_{\text{eff}} = 0.97$. This enrichment of the fissile material remains within the actual maximum fuel enrichment of 12%.

For Pu-Rhapsodie fuels, the mass control of fissile material to 262 g in the shuttle 108 (see § 5.3.4) allows the scenario of shuttle degradation following a fire to be covered. For a 100% $^{239}\text{Pu}_{\text{metal}}$ fissile material, with a reflection of 25 cm of lead followed by 15 cm of water, the admissible mass is 331 g, with an upper subcritical limit taken as $k_{\text{eff}} = 0.97$.

- The risk of deformation of geometrical dimensions due to falling loads,
 - the stability and local non-collapse of the civil engineering was checked for earthquake loads and snow and wind actions.
- The risks of double batching,
 - Due to the organizational measures put in place (double control, etc.), double batching is avoided.

6 TAKING INTO ACCOUNT THE FEEDBACK

6.1 Presence of Plastics in Channels

After opening the channels in block 116, it was found that the cases were sometimes placed in one or more plastic bags, as this material can be more moderating than water.

A criticality calculation was carried out to show that the shuttle's design was not compromised by the presence of plastic material surrounding the cases containing the fissile material.

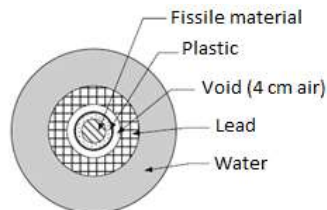


Figure 6. Criticality calculation model of shuttle 116 (with plastic taken into account)

6.2 Presence of Unpacked Fuel Elements

Unpackaged fuel elements were found in the block 116. These situations do not comply with the standard, which stipulates that a fuel element must be contained in a case, in particular in order to avoid the dispersion of fissile material in the shielded cell.

Unpackaged fuel elements were cased.

6.3 Discovery of Objects in a Supposedly Empty Channel

When opening a channel of the block 108, which was deemed to be empty according to the inventory and the display in place, for the re-storage of two cases present in the shuttle 108, the operators carried out a vacancy check of the channel in application of the operating procedure. Then, they noted the presence of objects inside the channel.

The 3 objects found were empty fuel transport containers stored in the canal without traceability.

6.4 Loss of Integrity of a Case in the Shielded Cell

After a case had been placed on the X-ray bench, the operators noticed that one of the case bottoms was no longer completely attached to the case body. This loss of integrity did not lead to the dispersion of material from the case.

A repackaging operation was carried out on this case, which did not contain any fuel.

6.5 Inconsistent Inventory

Despite the measures adopted in normal operation (traceability of the loading plan for the facility, monitoring of fissile material per channel, verification of the loading of the channel planned by another operator), during the dismantling of the fuel cases in channel 34 of block 108 (containing Pu-Rapsodie fuels), a discrepancy was noted in the inventory relating to the scheduling of the cases. Therefore, in application of a cautious approach based on feedback and the implementation of additional investigations, it was decided that certain cases would be dismantled step by step in order to consolidate the physical inventory of the block.

This event constituted a deviation from the expected course of operations. Beforehand, it was verified that the nuclear criticality limits would not be exceeded.

7 CONCLUSION

The preventive measures implemented and the taking into account of the operating feedback have made it possible to ensure the control of the nuclear criticality risk for the operations to assess and dismantle the fuels of blocks 108 and 116.