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FRAMATOME-ANP France UO2 Fuel Fabrication – Criticality Safety Analysis in the Light of the JCO Accident

M. Doucet *Framatome-ANP Fuel Technology Service*
michel.doucet@framatome-anp.com
S. Zheng *Framatome-ANP Fuel Technology Service*
J. Mouton *Framatome-ANP Fuel Fabrication Plant (FBFC)*
R. Porte *Framatome-ANP Fuel Fabrication Plant (FBFC)*

Abstract

In France the 1999' Tokai Mura criticality accident in Japan had a big impact on the nuclear fuel manufacturing facility community. Moreover this accident led to a large public discussion about all the nuclear facilities. The French Safety Authorities made strong requirements to the industrials to revisit completely their safety analysis files mainly those concerning nuclear fuels treatments. The FRAMATOME-ANP production of its French low enriched (5 w/o) UO2 fuel fabrication plant (FBFC/Romans) exceeds 1000 metric tons a year. Special attention was given to the emergency evacuation plan that should be followed in case of a criticality accident. If a criticality accident happens, site internal and external radioprotection requirements need to have an emergency evacuation plan showing the different routes where the absorbed doses will be as low as possible for people. The French Safety Authorities require also an update of the old based neutron source term accounting for state of the art methodology. UO2 blenders units contain a large amount of dry powder strictly controlled by moderation; a hypothetical water leakage inside one of these apparatus is simulated by increasing the water content of the powder. The resulted reactivity insertion is performed by several static calculations. The French IRSN/CEA CRISTAL codes are used to perform these static calculations. The kinetic criticality code POWDER simulates the power excursion versus time and determines the consequent total energy source term. MNCP4B performs the source term propagation (including neutrons and gamma) used to determine the isodose curves needed to define the emergency evacuation plant.

This paper deals with the approach FRAMATOME-ANP has taken to assess Safety Authorities demands using the more up to date calculation tools and methodology.

KEYWORDS: Criticality Accident, Kinetics, Neutron Source Term, Propagation, Isodose curves.

1. Introduction

The "Franco Belge de Fabrication de Combustible" (FBFC) Framatome-ANP France' PWR fuel fabrication plant located in Romans (France) produces around 1,500 assemblies a year. Fissile materials amounts in the factory are therefore important regarding the criticality safety. Knowing that the minimal critical mass of well moderated and reflected UO2 is less than 50 Kg for an enrichment of 5% in U235, there is a big concern about the criticality safety viewpoint. The 1999' JCO criticality accident reinforces the French Safety Authorities to carefully revisit the criticality safety files of the fuel fabrication and reprocessing plants. Till 1999 typical source term used for a criticality accident was based on an agreed value of 10^{18} fissions. The JCO' criticality accident has led to a power excursion releasing 2.5 10^{18} fissions. As this value exceeds the agreed one, industrials have been required to revisit in depth scenarios of criticality accidents.

On the other hand the Safety Analysis Reports (SAR) account for normal, incidental and accidental conditions leading to agreements for industrial operations. The accidental conditions accounted for in criticality studies often overstep the double contingency principle without breaching the criticality safety criteria. Nevertheless amazing and hypothetical accidental conditions has been used to define the inside and outside emergency evacuation procedures to allow an "as low as possible" people dose inhalation.

2. Calculation Codes and Methodology

The calculation methodology is divided into three main steps:

a. neutron static calculations,
b. neutron kinetic calculations,
c. neutron and photon propagation.

2.1 Neutron static calculations

The neutron static calculations are performed with the "industrial" route of the CRISTAL package (Figure 1) [1]. This package includes mainly the following modules: data preparation, spectral calculation for cross sections generation and 3D Monte Carlo calculations.

The goal of the static calculations is performed to reach a nearly critical situation by addition of different water contents in the UO2 powder blender or mixer. Thanks to the CRISTAL package (Cigales-Apollo2-Moret4 codes), parametric studies are able to determine a shape of increased reactivity versus water leaking inside a UO2 blender and a UO2 mixer simulated by an increase of the powder humidity. Those results will be the basic input data for the kinetic calculations

2.2 Neutron kinetic calculations

These calculations are made to determine the source term being representing the released energy in fissions. Knowing the fissile materials and its volume there are empirical models which can evaluate the emitted neutrons value (Barbry – Olsen – Nomura – models). Nevertheless Framatome-ANP decided to use a computational tool, called POWDER [2] developed by CEA/SRSC and AEA SRD based on the resolution of the following kinetic equation:

$$\frac{dn(t)}{dt}=\frac{(\rho(t))-\beta}{\Lambda}n(t)+\sum_i \lambda_i C_i(t)$$

$$\frac{dC_i(t)}{dt}=\frac{\beta_i}{\Lambda}n(t)-\lambda_i C_i(t)$$

Where:

- β is the delayed neutron fraction per neutron fission
- βi is the delayed neutron fraction coming from preceding nuclides for group i
- λi is the decay constant of the preceding nuclides for group i
- Ci (t) is relative to the preceding nuclides concentration for group i concentration
- n(t) is the energy released (fission/s) inside the medium
- Λ is the neutron generation lifetime
- ρ(t) is the medium global reactivity

The global reactivity ρ (t) is $\frac{K_{eff}-1}{K_{eff}}$, K_{eff} being the effective neutron multiplication factor. Global reactivity ρ (t) may be set to:

ρ(t) = external ρ(t) + feedback ρ(t)

With external ρ(t) being the reactivity coming from the water leakage inside the UO2 powder and feedback ρ(t) being the accounting for thermal expansion, Döppler effect, water temperature effect ...

More explanation on this methodology can be found in [3].

2.3 Photons propagation

Neutron energy release calculated in section 2.2 is then used to normalize the propagation calculation performed with the well known MCNP4B 3D Monte Carlo code [4]. The different buildings in the neighbourhood of the potential accident workshop are roughly described to ensure a penalizing neutrons and photons propagations inside the fuel plant as well as outside this latter one. Equivalent dose H for particles of energy E is derived from absorbed dose and the so called quality factor Q taken from the updated ICRP60.

For the emergency evacuation plan we used the following values:

- Evacuation limit (plant) : 50 mSv
- Preventive limit (population) : 10 mSv

3. Calculation results

3.1. Static calculations

3.1.1. UO2 blender case

The goal of these calculations is to increase the reactivity to be as close as possible regarding the criticality. A set of calculations is performed with the following hypothesis:

The UO2 blender is simulated by an unreflected cylinder,

- Three tons of 5% enriched UO2,
- Powder mass densities: 1.0 – 1.5 – 2.5 g/cm3,
- H/U variation to reach Keff = 0.999

Results are given Table 1

Table 1

UO2 density (g/cm^3)	Powder volume (cm^3)	Cylinder height (cm)	Cylinder radius (cm)	H/U	K_∞ Apollo2	K_{eff} Moret4
2.5	1.2E+6	173.45	46.93	3.04	1.33	0.999
1.5	2.0E+6	215.62	54.34	4.58	1.39	0.999
1.0	3.0E+6	254.70	61.23	6.35	1.43	0.999

3.1.2 UO2 mixer case

The hypothesis for the UO2 mixer case are the same as the UO2 blender case ones excepted the mass content which is in this case 800 Kg.

Results are given Table 2

Table 2

UO2 density (g/cm^3)	Powder volume (cm^3)	Cylinder height (cm)	Cylinder radius (cm)	H/U	K_∞ Apollo2	K_{eff} Moret4
1.0	8.0E+5	156.76	40.30	10.65	1.45	0.999

3.2. Kinetic calculations

3.2.1. UO2 blender case

The goal of these calculations is to determine the neutron source term, integrated fission number over the accident time evolution.

A set of POWDER calculations is performed with the following hypothesis:

- Cylinder dimensions similar to the static calculations ones,
- Three tons of 5% enriched UO2,
- "Wet" powder mass density corresponding to the H/U ratio leading to Keff = 0.999,
- Reactivity insertion simulated by a water leakage inside the UO2 blender.

A close relation exists between the water leakage and the reactivity increase; in this case the equivalent of a few litres of water/minute is taken as a 0.01 \$/s reactivity insertion [5].

Results are given Table 3

Table 3

Dry UO2 density (g/cm^3)	Wet UO2 density (g/cm^3)	Accident duration (s)	Energy released (fission number)
2.5	2.753	392	9.9E+18
1.5	1.729	471	1.6E+19
1.0	1.212	529	2.2E+19

3.2.2. UO2 mixer case

The hypothesis and the goal of these calculations are the same as for the blender case ones excepted the mass content which is in this case 800 Kg. The penalizing case of the UO2 blender case corresponding to a "dry" powder mass density of 1.0 g/cm3 is retained here.

Results are given Table 4

Table 4

Dry UO2 density (g/cm^3)	Wet UO2 density (g/cm^3)	Accident duration (s)	Energy released (fission number)
1.0	1.355	505	6.3E+18

4. Isodose curves

The isodose curves are drawn accounting for the accident energy released as well as the workshop positioning inside the fuel fabrication plant. For the higher energy release, i.e. 2.2E+19 fissions, the Table 5 hereafter gives as a function of the four cardinal directions the distances for typical dose values:

Table 5

	500 mSv	100 mSv	50 mSv	10 mSv	5 mSv	1 mSv
North (m)	55	110	145	260	325	500
South (m)	140	255	315	480	560	760
East (m)	65	80	110	245	320	510
West (m)	33	65	90	165	220	395

Keeping in mind those results we can draw the following conclusions:

- The closest inhabitant area is 600 m far away from the site and the dose limit of 10 mSv is always met whatever the cardinal direction.
- For the dose limit of 50 mSv at the border of the site, some breachings of the criterion appear. Radioprotection improvements have been already engaged to decrease the dose values to ensure the criterion in the concerned cardinal directions.

5. Conclusion

Thanks to the various safety operational features taken in the fuel fabrication plant such an accident is not possible. Nevertheless the exercise presented in this paper show the capability of the FRAMATOME-ANP France codes and methodology to handle such a situation to determine the risks of dose inhalation for people inside and outside of the site

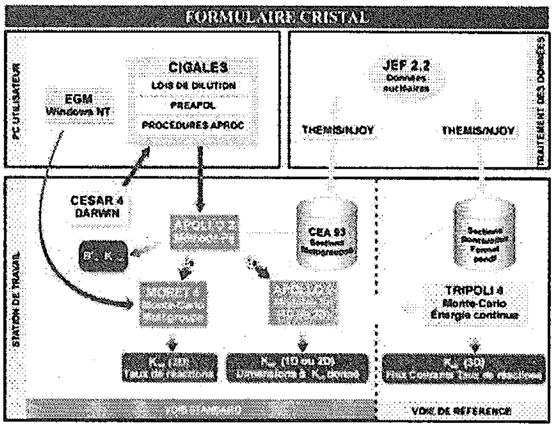

Figure 1

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