Recycling facility Periodic Safety Review

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1. Periodic Safety Review

- **A legal requirement**
  
  “The licensee of a nuclear installation carries out a safety reassessment of its facility periodically, [...]. The periodic safety review should occur every ten years.”

  *French Environmental Code*

- **A two-step process**
  
  1. A review of the facility’s *conformity* with its reference safety frame
  2. A *safety reassessment* for each risk taking into account the state of the art

Which **methodology** do we have to choose to achieve the criticality part of a PSR?

- **Methodology designed for UP3-A Periodic Safety Review**
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2. UP3-A, a recycling facility

<table>
<thead>
<tr>
<th>Some of the process steps</th>
<th>Fissile materials</th>
<th>Pieces of equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiving, unloading and storage used fuels</td>
<td>(U+Pu)O₂ in used fuels</td>
<td>Fuel assemblies baskets</td>
</tr>
<tr>
<td>Dissolution</td>
<td>(U+Pu)O₂ in nitric solution</td>
<td>Dissolvers</td>
</tr>
<tr>
<td>Clarification</td>
<td>Undissolved (U+Pu)O₂</td>
<td>Centrifugal Clarifier</td>
</tr>
<tr>
<td>PF, Pu and U separation</td>
<td>(U+Pu) in nitric solution</td>
<td>Pulsed columns, mixer-settlers, annular vessels…</td>
</tr>
<tr>
<td>Pu purification</td>
<td>Pu nitrate</td>
<td>Pulsed columns, mixer-settlers, annular vessels…</td>
</tr>
<tr>
<td>Oxide conversion</td>
<td>PuO₂F₂, PuO₂</td>
<td>Precipitators, filter, calciner…</td>
</tr>
<tr>
<td>Hulls and end-pieces compacting and storage</td>
<td>(U+Pu)O₂ in hulls</td>
<td>Hulls containers in storage</td>
</tr>
</tbody>
</table>

UP3-A is characterized by a **large variety** of process and pieces of equipment (geometrically safe or favorable)

A **full-scale** approach of the UP3-A criticality safety reassessment is it the best methodology for such a facility?
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3. PSR methodology

Purpose of the proposed PSR methodology

- To have an overall view of the safety frame, especially of the criticality calculation notes
- To focus the resources on the Nuclear Criticality Safety issues

A three-step methodology

1. Evaluation of impacts, on nuclear criticality-safety studies, of conformity review, aging effects, and state of the art of criticality calculations
2. Identification of sensitive systems from the above evaluated impacts and safety margins
3. Additional studies for sensitive systems

Methodology designed for geometrically safe or favorable pieces of equipment optionally combined with a neutron absorber
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4. Step 1: Impacts evaluation on the safety frame

4.1. Conformity review

- Purpose of a conformity review
  
  To verify that the actual pieces of equipment are consistent with the design safety requirements of the reference safety frame.

- NCSDT: a key document for the conformity review
  
  - Released for each equipment before commissioning
  - Ensures that the criticality modelling bounds reality

- Process of a conformity review
  
  1. Comparison of “as built” dimensions and corrosion allowances to NCSDT information
  2. If discrepancies are highlighted, NCSDT are updated and possible non-compliances to criticality-safety requirements are highlighted
  3. To be solved, the highlighted non-compliances are inputs for the step 2 of the PSR Methodology
4. Step 1: Impacts evaluation on the safety frame
4.2. Aging effects analysis

- Purpose of aging analysis effects

To study how aging mechanisms involved can affect the safety functions of an equipment during an average operation period at least consistent with the plant’s future operations.

- Aging effects analysis: a sharp analysis

  - Performing an inventory of the design features, the operating conditions and their historical changes for each equipment
  - Identification of aging effect involved
  - Rating of aging effect mechanism knowledge

- Action plans can be define to support aging effects analysis and prevent future non-compliances

- Possible future non-compliances are inputs for the step 2 of the PSR Methodology
4. Step 1: Impacts evaluation on the safety frame

4.3. Criticality calculations’ state of the art

Definition of criticality calculations’ state of the art

- The latest best technical practices
- The latest criticality codes or packages including V&V reports

Discrepancies between UP3-A criticality calculations notes and the current state of the art

- Pu isotopic composition
- Density laws of actinide nitrates
- Water content in concrete
- The CRISTAL package
4. Step 1: Impacts evaluation on the safety frame

4.3.a. Pu isotopic composition

- Recycling Pu isotopic mass composition **historically** used for UP3-A design
  
  \[
  83 \% \text{Pu}^{239} / 17 \% \text{Pu}^{240}
  \]
  
  with \{Hansen & Roach\} or \{JEF1/CEA86 + APOLLO1\} \(\chi\)-sections

- Recycling Pu isotopic mass composition **currently** used
  
  \[
  71 \% \text{Pu}^{239} / 17 \% \text{Pu}^{240} / 11 \% \text{Pu}^{241} / 1 \% \text{Pu}^{242}
  \]
  
  with \{JEF 2.2/CEA93/V6 + APOLLO2\} \(\chi\)-sections

For all UP3-A criticality calculations notes, a generic bias, \(\Delta k_{\text{eff}}(\text{Pu})\), bounding impacts on \(k_{\text{eff}}\) due to evolutions from historical to current Pu isotopic mass composition is evaluated.
4. Step 1: Impacts evaluation on the safety frame

4.3.b. Density law of actinide nitrates

- Density laws of actinide nitrates have been evolving since the design stage of UP3-A

- The density law of actinide nitrates considered in CRISTAL V1.2 package is the one known as isopiestic law

For all UP3-A criticality calculations notes, a generic bias, $\Delta k_{\text{eff}}(\text{nitrates})$, bounding impacts on $k_{\text{eff}}$ due to evolutions from old actinide nitrates density laws to the isopiestic one is evaluated
4. Step 1: Impacts evaluation on the safety frame

4.3.c. Water content in concrete

- For the UP3-A design stage, the concrete was modeled by a Portland concrete with a 8.93 wt. % of water

- The water content value in concrete leading to a maximum $k_{eff}$ value depends on:
  - the kind of configuration studied
  - the concrete composition modeling

The current best practice to model the water content in concrete is to determine for each configuration the optimum water content value.

For all UP3-A criticality calculations notes, a generic bias, $\Delta k_{eff(concrete)}$, bounding impacts on $k_{eff}$ due to evolutions from old water content in concrete hypotheses to the current best practice is evaluated.
4. Step 1: Impacts evaluation on the safety frame
4.3.d. CRISTAL Package

- Some of the criticality codes / packages used during the UP3-A design stage

- CRISTAL V1.2, the current state of the art of CRISTAL Package

<table>
<thead>
<tr>
<th>X-sections library for fissile media</th>
<th>X-sections library for non fissile media</th>
<th>$k_{\text{eff}}$ calculation code</th>
</tr>
</thead>
<tbody>
<tr>
<td>APOLLO2 V2.5.5 / CEA93.V6</td>
<td>APOLLO2 V2.5.5 / CEA93.V6</td>
<td>APOLLO2 (Sn-keff)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>APOLLO2 (Sn-Normes)</td>
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<td></td>
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<td>MORET 4 V4.B.4</td>
</tr>
<tr>
<td>JEF 2.2</td>
<td>JEF 2.2</td>
<td>TRIPOLI-4.4</td>
</tr>
</tbody>
</table>

For all UP3-A criticality calculations performed with old codes / packages, a generic bias, $\Delta k_{\text{eff}}(\text{code})$, bounding impacts on $k_{\text{eff}}$ due to evolutions from old codes / packages to the current state of the art is evaluated.
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5. Step 2: Identification of sensitive systems

5.1. Margins of safety

- **The modeling margins**: qualitative margins related to differences between
  - The fissile media characteristics
  - The geometry modeling
  and
  - The reality

- **The calculation margins**: quantitative margins related to differences between
  - the maximal reactivity of the conservative configuration \((k_{\text{eff}} + 3\sigma)_{\text{max}}\) or \(k_{\text{eff}}\)
  and
  - the Nuclear Criticality Safety Acceptance Criterion (NCSAC)

\[
\Delta k_{\text{eff}}(\text{margin}) = \text{NCSAC} - (k_{\text{eff}} + 3\sigma)_{\text{max}}, \text{ for a Monte Carlo calculation}
\]

or

\[
\Delta k_{\text{eff}}(\text{margin}) = \text{NCSAC} - k_{\text{eff}}, \text{ for a deterministic calculation}
\]
5. Step 2: Identification of sensitive systems

5.2. Identification methodology

1. Determination of the calculation hypotheses of the conservative configurations

2. Evaluation, for each conservative configurations, of a state of the art bias, $\Delta_{SOTA}$

   $\Delta_{SOTA} = \text{NCSAC} - [(k_{eff} + 3\sigma)_{\text{max}} + \Delta k_{eff}(\text{concrete}) + \Delta k_{eff}(\text{Pu}) + \Delta k_{eff}(\text{nitrates}) + \Delta k_{eff}(\text{code}) + \Delta k_{eff}(\text{margin})]

3. Identification of sensitive systems

   If
   - $\Delta_{SOTA} \geq K$
   - Geometrical hypotheses of calculation note bound conformity and ageing studies conclusions

   The studied system is not a sensitive system

   For all other cases, a further analysis is conducted, taking into account qualitative margins. Following this analysis, the safety engineer decides if the system is to be considered as a sensitive one
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- For sensitive systems, calculation notes are updated taking into account
  - the state of the art of criticality calculations
  - the geometrical hypotheses by taking the conclusions of conformity and ageing studies

- If the NCSAC is still not respected, new hypotheses such as process or geometrical hypotheses could have to be considered
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The proposed PSR methodology allows at the same time

1. To have an overall view of the safety frame, especially criticality calculation notes
2. To focus the resources on the Nuclear Criticality Safety issues

Key points to achieve successfully the criticality part of a PSR

- A deep knowledge about the facility by the criticality safety engineers
- A close collaboration with the operator

The current application of this methodology on the UP3 safety frame shows that there’s no major impact of conformity, aging studies and state of the art on UP3 criticality calculation notes conclusions

Anticipation of future evolutions by engineering teams during the UP3 design stages
Some of the criticality codes / packages used during the UP3-A design stage

<table>
<thead>
<tr>
<th>Package</th>
<th>X-sections library for fissile media</th>
<th>X-sections library for non fissile media</th>
<th>$k_{\text{eff}}$ calculation code</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HANSEN &amp; ROACH</td>
<td>HANSEN &amp; ROACH</td>
<td>DTF IV</td>
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<td>HANSEN &amp; ROACH</td>
<td>HANSEN &amp; ROACH</td>
<td>MORET I / II</td>
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<tr>
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<td>APOLLO1 / CEA86</td>
<td>HANSEN &amp; ROACH</td>
<td>MORET I / II / III</td>
</tr>
<tr>
<td>SCALE 4</td>
<td>ENDF-BIV</td>
<td>ENDF-BIV</td>
<td>KENO Va</td>
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<tr>
<td>CRISTAL V1.2</td>
<td>APOLLO2 V2.4.3 / CEA93.V4</td>
<td>APOLLO2 V2.4.3 / CEA93.V4</td>
<td>APOLLO2 (Sn-$k_{\text{eff}}$)</td>
</tr>
<tr>
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<td>APOLLO2 V2.4.3 / CEA93.V4</td>
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<td>CRISTAL V0.2</td>
<td>APOLLO2 V2.4.3 / CEA93.V4</td>
<td>APOLLO2 V2.4.3 / CEA93.V4</td>
<td>MORET 4 V4.A.6</td>
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<tr>
<td>CRISTAL V1.0</td>
<td>APOLLO2 V2.5.4 / CEA93.V6</td>
<td>APOLLO2 V2.5.4 / CEA93.V6</td>
<td>MORET 4 V4.B.2</td>
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