Criticality Safety Standard for Final Disposal of Nuclear Fuel

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General Information on the Standard

Criticality safety standard for final disposal of nuclear fuel

- Integral, risk-informed approach for the criticality safety analysis
- Independent of site conditions and host rock
- Application of burnup credit (BUC) is explicitely allowed
- Draft published in February 2011, currently in review
- Publication expected for 2012

Vast range of nuclear fuels that have to be taken into account

- LWR fuels (unirradiated and irradiated); western design UO_2 and MOX, VVER UO_2
- FBR (Fast Breeder Reactor) fuel – MOX fuel with high fissile content
- HTR (High Temperature Reactor) and Thorium-HTR fuel
- MTR (Material Test Reactor) and research reactor fuel – including HEU fuel

Double Task: Pre- and Post-Closure Phase

Different requirements for the operational (pre-closure) and the post-closure phase of the facility have to be handled in a consistent way

- Application of the single failure criterion for the operational phase
- Analysis of chances and possible consequences of a criticality excursions under given scenarios for the post-closure phase
- Consistent mathematical framework with risk-informed analysis for both phases

Formulation of possible scenarios and definition of time scales for the safety analysis of the post-closure phase

- Analysis of a given scenario less of a challenge than formulating possible scenarios and estimating their probability of occurrence
- Inherent criticality risk diminishes slowly compared with civilizational or even geological (e.g. ice ages) time scales – the halflife of ^{235}U is 0.7 billion years

Pre-Closure Phase: Single Failure Criterion (SFC)

SFC states that a single failure must not result in a criticality event

- Generally valid for all fuel management systems outside the reactor core

Compliance with the SFC is achieved by a hierarchy of safety measures:

- Passive measures
- Active engineering measures that are initiated automatically
- Active engineering measures brought into action manually
- administrative measures

German criticality safety standard (DIN 25403-1): For non-compliance, probability and consequences of a criticality event have to be determined and it has to be demonstrated that the event is ‘not credible’

- An event with a probability of occurrence $P \leq 10^{-6}$ can be regarded as ‘not credible’

Pre-Closure Phase: Safety Criterion $P_{crit} \leq L = 10^{-6}$

Probability of criticality P_{crit} under a given scenario S:

$$P_{crit} = P\left(k_{eff} \geq (1 - \delta k_M) \middle| S\right) \cdot P(S)$$

The value of k_{eff} can only be determined with limited accuracy due to

- uncertainties and correlations in the nuclear data used in the computation codes
- uncertainties in the characteristic parameters of a fuel unit or configuration
- uncertainties in the characteristics benchmark experiments used for code validation
- inherent inaccuracies of the computation codes

The value of the administrative safety margin δk_M is based on whether and to what extent the uncertainties in the nuclear data are considered

- δk_M can range from 0.005 (full analysis) to 0.02 (no study of data uncertainties)

Transition from the Pre- to the Post-Closure Phase

At the end of the pre-closure phase, all fuel units are subcritical. Turning this into a critical or supercritical state requires a change of the fuel units that can be caused by degradation of technical barriers and/or the loss of natural barriers

- Changes to the fuel includes changes in their concentration, composition, geometry, moderation and/or neutronic reflection
- Technical barriers include the cladding of fuel rods, storage casks, sealing of storage drifts, etc. Structural and (especially) neutron absorber material is also included.
- Failures or complete loss of natural barriers can result from geological and climatical developments. The most important consequence is water ingress, causing increased neutron moderation and the possible accumulation of fissile matter.

Assessment of these changes necessitates the development of scenarios.

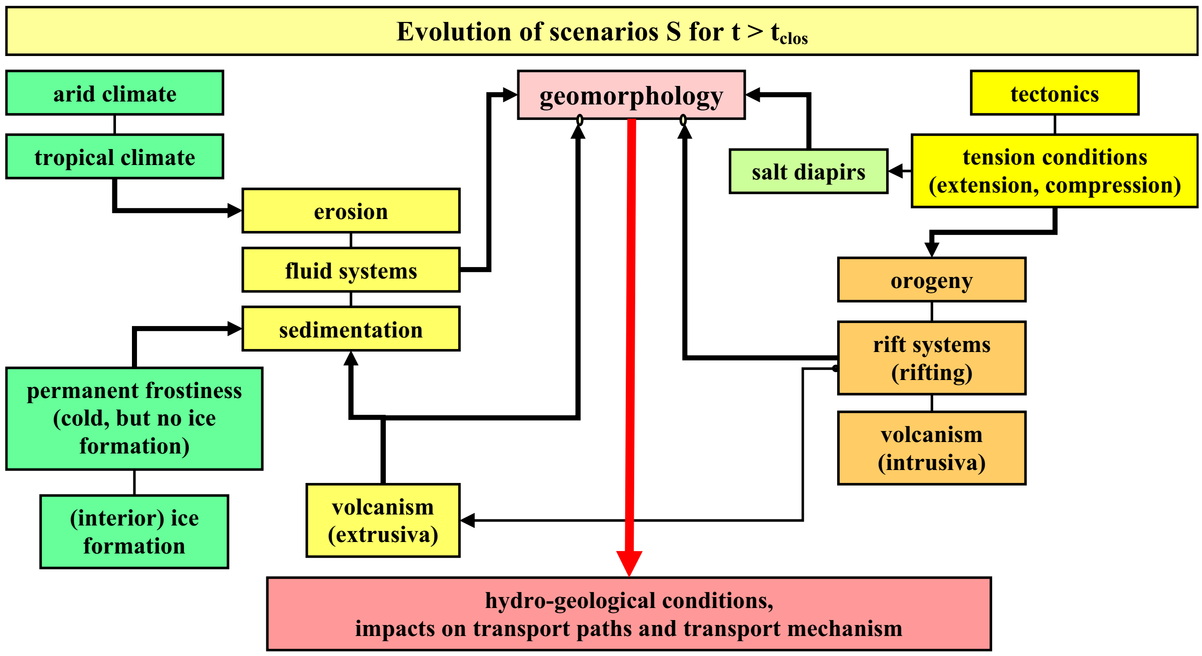
Scenarios for the Post-Closure Phase

Scenarios consist of hypothetically possible future situations or sequences of future events; they are not to be confused with predictions. The criticality safety assessment has to identify scenarios with increases in k_{eff} and estimate their probability of occurrence.

Whereas the operational phase will last for a few decades, the time scale for the post-closure phase extends over geological time spans, at least regarding the development of the inherent criticality risk of spent fuel.

Scenario development requires knowledge from many disciplines beyond neutron physics. The standard provides a comprehensive overview (in the form of flow diagrams) of the various processes that may have an impact on the facility. This is restricted to information on *what* processes exist, not guidelines on *how* to integrate them into scenario development.

Overview of Tectonic Processes and Climatic Conditions determining the Geomorphology



Post-Closure Time Scale Issues

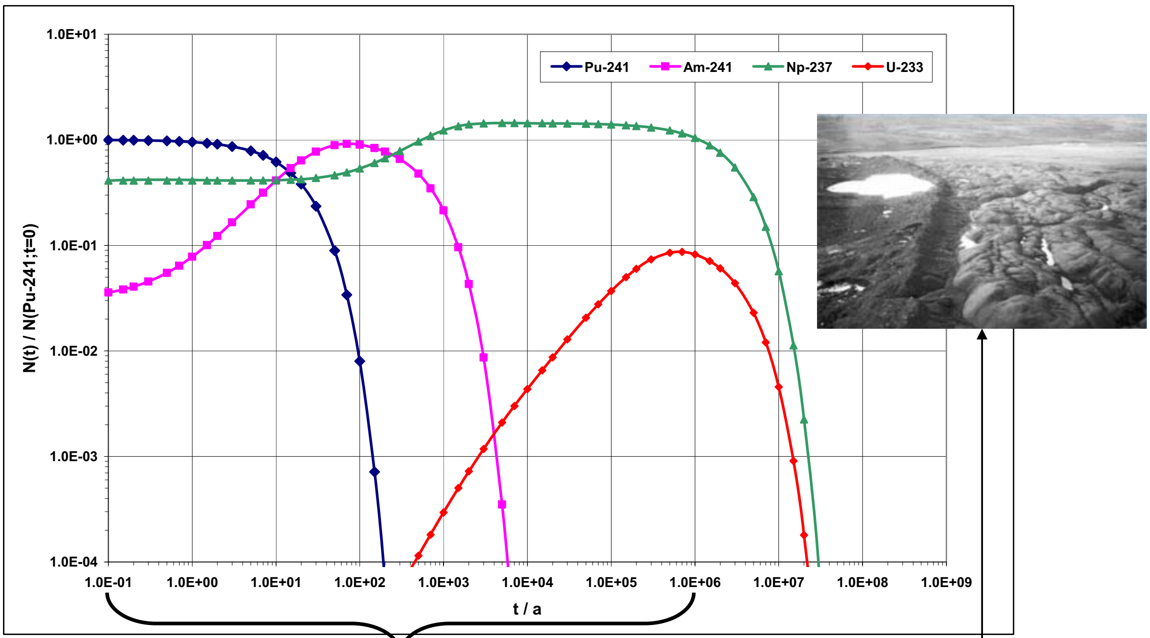
Defining a period of analysis (e.g. 10^4 or 10^6 years after closure) disregards the physical basis of the problem. 99.9% of the original ^{235}U content will still be present after 10^6 years. Other decay processes can even increase the reactivity of the fuel (e.g. ^{233}U build-up).

The time period to be analyzed depends on

- Isotopic inventory of the fuel storage units
- Changes of the storage units due to tectonics or climate
- Facility host rock

In any case, it is questionable whether the exclusion of criticality events over such enormous time scales is possible. Accordingly, the criticality safety criterion for the pre- and post-closure phase are not the same.

Production of ^{233}U from ^{241}Pu and ^{241}Am



approx. 10 glacial epochs to be expected (Milankovitch)

Post-Closure Phase: Safety Criterion $P_{crit} \leq L(t)$

$$P_{crit} = P\left(k_{eff} \geq (1 - \delta k_M) \middle| S\right) \cdot P(S)$$

P_{crit} is estimated along the same principles as for the operational phase. P(S) will generally be harder to determine with increasing time. There will be a scenario-dependent time t_S when P(S) can not be reasonably estimated anymore.

To compensate for this, the limit L is set higher than for the operational phase, with a gradual increase of L with time up to $L = 10^{-4}$.

Furthermore, the possible occurrence of a criticality event for times $t > t_S$ can be acceptable unless the consequences violate the safe containment.

This approach is motivated by a balanced perspective on the total risk.

- The only alternative would be to compensate with practical measures that increase the risk during the operational phase (e.g. smaller fuel units, downblending)

Step-by-Step Assessment for the Post-Closure Phase