Annex X

Summary of the Topical Session on
"Criticality and Safeguards in DGRs"

Chair/Rapporteur: Ulrich Noseck, GRS, D

Chair/Rapporteur: Wilhelm Bollingerfehr, DBETEC, D

Introduction and scope of the topical session

The topical session dealt with experiences from assessments of criticality safety and the application of safeguards in the different member countries of the IGSC. With respect to criticality the objectives were to:

1. explore how members are planning to manage or have demonstrated criticality safety in the post-closure phase of a repository;
2. identify dependencies on host rock formation, repository design, waste package materials, etc.;
3. compile and evaluate measures to guarantee long-term criticality safety;
4. evaluate regulatory views on how to demonstrate criticality safety for the repository.

For Safeguards the objectives were to:

5. compile and evaluate strategies to provide safeguards for the nuclear material in the repository with or without retrievability requirements (according to national legislation);
6. evaluate regulatory views on how to demonstrate safeguards for the repository.

The following presentations were given and can be found at https://www.oecd-nea.org/download/igsc/igsc-19/index.html:

- Criticality effects of long term changes in material composition and geometry in a damaged disposal canister. *Kastriot Spahiu, Lennart Agrenius, SKB, Sweden*
- Long-term criticality safety: challenges and research, German perspective. *Robert Kilger, GRS, Germany*
- Study on criticality in deep geological disposal in Japan. *Hitoshi Makino, JAEA, Japan*
- Demonstrating post-closure criticality safety of the UK geological disposal facility. *Robert Winsley, RWM, UK*
- Post-closure nuclear criticality safety assessment for the French Cigéo clay repository. *Clement Lopez, Andra, France*
- Post-closure Criticality Review and Safeguards Considerations for a Proposed High-level Radioactive Waste Repository. *Jack Gwo, US NRC*
- Status of Criticality and Safeguards Management in Canada. *Helen Leon, Neale Hunt NWMO, Canada*
- Posiva's approach to criticality management and safeguards. Anssu Ranta Aho (TVO), *Barbara Pastina, Marie Lahti Posiva, Finland*
- Safeguarding geological repositories in the context of national legislation – the German case. *Irmgard Niemeyer, FZJ, Germany*
- Application of Safeguards to Geological Repositories. *Marius Davainis, IAEA*

The main results from the presentations and discussion are summarized in the following.

1. Criticality

Regulatory aspects

The regulatory requirements given for the assessment of long-term criticality safety differ widely for each country. In some countries only very general requirements are given, e.g. in Germany, where it is stated that „… the exclusion of self-sustaining chain reactions for both probable and less probable developments must be proven”. There is no specific requirement how this has to be shown or any specific target value given for the effective neutron multiplication factor, k_{eff}, which must not be exceeded. However, the German regulations are currently under revision and it is expected that some more concrete requirements with respect to criticality will be included. In Japan, where the waste policy was based on reprocessing and vitrification of spent fuel, more back-end flexibility was recommended after the Fukushima accident. As a consequence direct disposal is now under the R&D stage, but there are no specific regulatory requirements with respect to direct disposal including criticality yet.

In other countries the requirements are formulated in a very specific way. In Sweden the effective neutron multiplication factor, k_{eff}, including uncertainties should be < 0.95 in the repository and <0.98 in unlikely events or accidents. In Finland such requirements are so far only given for repository operation. STUK YVL Guide B.4 states that the effective multiplication factor k_{eff} will not exceed the value 0.95 under normal conditions or in anticipated operational occurrences and the value 0.98 in other design basis scenarios. Another requirement from the Finish YVL guide D.5 states that “… the spent nuclear fuel contained in a disposal canister shall remain subcritical also in the long term. The design shall accommodate conditions where the leak-tightness of the container has been lost and the container has sustained mechanical or corrosion-induced deformations”. This implies very specific requirements on the container construction with respect to criticality safety.

The environment agencies’ Guidance on Requirements for Authorisation (GRA) for a geological disposal facility in the UK requires a demonstration that “the possibility of a local accumulation of fissile material such as to produce a neutron chain reaction is not a significant concern” and it further states that “the environmental safety case should also investigate, as a ‘what-if’ scenario, the impact of a postulated criticality event on the performance of the disposal system)“.

Scenarios

For the demonstration of long-term safety as well as of criticality safety it is needed to make plausible assumptions of the future evolution of the repository, i.e. to define scenarios. For long-term safety assessment usually a transparent and traceable approach is applied to derive probable and less probable scenarios to be considered in the calculation cases.

For demonstration of post-closure criticality safety such a systematic and transparent approach is not available so far and quite different approaches with respect to scenarios are applied. The evaluation of the presentations indicates that the stage of the repository programme as well as regulatory requirements influence the scenario selection. In Germany, where the repository programme is still in a pre-siting stage, for the recent VSG (Vorläufige Sicherheitsanalyse Gorleben) study partly very conservative assumptions with respect to the evolution of the repository system as for example an early flooding of the waste containers are taken as a basis. This process has not been identified as being part of a probable or less probable scenario and was not considered in the calculations for long-term safety assessment.

On the other hand for demonstration criticality safety in the Swedish safety case, where the Forsmark site is already selected and the repository process is approaching the construction phase, the same scenarios, namely (i) canister failure due to corrosion (for advective conditions caused by bentonite erosion) and (ii) canister failure due to shear load caused by a large earthquake, have been considered in criticality safety and long-term safety assessment. Nevertheless the assumption that one container is filled with water after a 100 y is also very conservative.

Transparency and credibility might be increased, when scenarios applied for both, long-term and criticality safety, are more consistent. A step towards a more systematic approach of scenario derivation for consideration of criticality events might also be the use of features, events and processes (FEP). FEP catalogues are widely used in scenario derivation for long-term safety assessment to increase transparency and reach comprehensiveness. Such A FEP based approach was introduced by the US presentation, where 16 FEP on criticality were identified and documented.

However, as already discussed above, in some countries the selection of specific scenarios for demonstration of criticality safety is required by legislation. The UK guidance demands the investigation of the consequences of a what-if scenario assuming a postulated criticality event in the repository. The analysis of such a criticality event in the repository was also analysed in the French, Swedish and Japanese study. Typical results from the UK study showed that consequences from quasi-steady-state transient criticality events of one container occur localised, the power is below 2kW and a temperature rise in the host formation of above 10°C is limited to an area of just a few meters.

Similarities in the approaches are observed with respect to the following. Nearly all studies consider the potential of criticality within and outside of the canisters. Inside the flooded canister it is usually distinguished between an intact waste form on the one hand and the formation of corrosion products and degraded/fragmented fuel on the other hand. For the latter case in some studies a homogeneous mixture of fuel, corroded metal and water was assumed and in other studies more thoughts were given to the formation and distribution of the corrosion products. However, as shown in the Swedish study, there is a lack of data especially for distribution and hydration of corrosion products formed after very large time spans. For these not even archaeological data exist. In such cases expert judgement was used to define the considered systems. Outside the container possible accumulation processes for the fissile isotopes are identified and the potential for the system to become critical is estimated for them.

Methodological approach

Generally, it seems that standardized approaches for criticality assessment for DGR are not available but methods have been adapted from nuclear industry applications.

Deterministic calculations are always performed and necessary in any case. However, for consideration of parameter uncertainties several organisations perform also probabilistic calculations, complementing and supporting the deterministic calculation cases. Another wide fold strategy to consider uncertainties is the use of conservative assumptions. Nearly all studies assume a more or less early flooding of the container. Since the fissile isotope ^{239}Pu decays to the fissile isotope ^{235}U in many cases the most critical point in time, where the highest effective neutron multiplication factor occurs, is addressed. Another example for very conservative assumptions was given in the Canadian study. In the considered scenario a fast dissolution of spent fuel, which is only possible under oxidizing conditions, is assumed. Dissolved uranium is then efficiently accumulated by immobilization; such a process is only expected under reducing conditions. This scenario causes highest consequences and even in this case it was shown that no criticality occurred. But, such a scenario is inconsistent and not realistic; hence it was recommended to address more realistic and consistent scenarios, unless otherwise required by regulations.

Host-rock, design and material specific aspects

One interesting observation is related to large differences in criticality safety demonstration caused by specific characteristics of the host-rock, the design or the waste material itself. With respect to the host rock the occurrence of highly mineralized water is a clear advantage with respect to criticality safety. This is particularly due to the neutron absorbing properties and the high natural abundance of 75.76 % of the isotope ^{35}Cl. Due to its high thermal absorption cross section of 43.7 barn it acts as a neutron absorber significantly decreasing the reactivity and therewith the probability of criticality. This is illustrated by reduction of the effective neutron multiplication factor, k_{eff} in saturated brines compared to systems with pure water, as for example investigated in the German study.

For the container design typically the main criteria origin from operational requirements and not from criticality considerations. However, there are also design issues, which are of relevance for criticality safety and in order to avoid a high potential for criticality (preliminary) criticality assessments at an early stage of container conceptualization are recommended. The number of fuel assemblies per container is of course important and some basic investigations for representative spent fuel containers have been performed for example in Japan. In this context it is of relevance, how much burn-up credit need to be taken into account for reaching criticality safety. Usually burn-up credit is allowed to be included but it is not mandatory. And it need also to be considered that some engineering materials like concrete or bentonite can act as reflectors and therewith negatively impact the occurrence probability of criticality.

Another issue on container design is related to the direct disposal of the transport container for spent fuel elements Castor, which is currently under discussion as one disposal option in Germany. To avoid criticality in the repository it is proposed to use magnetite infill in the void volumes of the Castor container.

Finally, it is the waste itself, whose properties impact the potential for criticality. For example, the majority of the Canadian fuel wastes from nuclear power plants are CANDU bundles. CANDU fuel is not enriched and contains the natural fraction of U-235 of 0.72 wt._%, i.e. much less fissile material compared to spent fuel. Such CANDU fuel cannot go critical under any realistic scenarios, neither in the used fuel packing plant, nor in the deep geological repository. The same is true for vitrified waste from reprocessing, which represents by far the majority of the high-level radioactive waste in France. The result of the French criticality safety assessment for this type of waste, where uranium and plutonium is partitioned from the waste, showed that the likelihood of a criticality in the repository is indeed impossible.

2. Safeguards

Safeguards for fission material are mandatory for deep geological repositories. Already in 1988 experts recommended that IAEA should not terminate safeguards on spent fuel before or after emplacement in a geological repository.

Particularly during the last technologies have been compiled and described which are potentially useful for safeguarding geological repositories. Within the project ASTOR (Application of Safeguards to Geological Repositories) proposed technics and methods have been compiled (ASTOR report, IAEA STR-384, 2016) as

- Design Information Verification
- Non-Destructive Assay Verification
- Containment & Surveillance
- Satellite Imagery & Geophysical Techniques
- Long-Term Data Management

In order to implement the IAEA safeguards continuous dialogue between all stakeholders – the state, operators and IAEA is desirable. An example is the EPGR project in Finland and Sweden, where safeguard approaches for encapsulation plants and geological repositories are developed and the appropriate equipment and technologies are tested integrated and installed in cooperation with IAEA..

General challenges are the exceptionally long life cycle of the projects, the application of “best available” techniques for spent fuel measurements and maintaining continuity of knowledge while transporting disposal canisters. Further challenges for deep geological repositories are that

- nuclear material will not be accessible for direct verification,
- disposal canisters will become inaccessible after a tunnel is backfilled or the repository is closed,
- the design of the facility will not be frozen – excavation of new tunnels will be taking place at the same time as other tunnels are being backfilled,
- only a small part of the facility will be visible above ground,
- undeclared areas can be ‘hidden’ behind declared tunnels,
- access routes to the repository may be excavated before or during its operation life.

The status of implementation of safeguards concepts and measures widely differs. In regulations of some countries safeguards are not specifically addressed (e.g. Canada) whereas in other countries they are explicitly mentioned as in different Codes of Federal Regulations (CFR) in the USA. In the guide on nuclear safety in Finland specific requirements related to the disposal of spent nuclear fuel are contained. Several specific requirements about accountancy and control systems during the operational phase were described. A strategy for providing safeguards after repository closure, including responsibilities, information about the repository, and documentation was given. Retrievability is included as a condition in the construction license. It considers the identification of disposal canisters and the control of backward flow of nuclear material.