# MULTINATIONAL COOPERATION iNITIATIVE

# ON POST-CLOSURE CRITICALITY SAFETY

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**Abstract**

Demonstrating the criticality safety of a final disposal concept in the post-closure phase, i.e. over very long timescales, is a complex and unique endeavour for many, if not all, Waste Management Organisations (WMO) that have to dispose of spent fuel and other radioactive waste. While certain matters are intrinsically related to the particularities of each individual disposal concept or facility, the WMOs do address many similar aspects. Therefore, the sharing of knowledge, experience and innovative ideas between them has clear benefits. For instance, the envisioned exchange would enable the development of a methodology to perform meaningful comparisons and increase understanding between the different WMO approaches to assessing criticality safety. This would facilitate an informative comparison and validation between their respective results. Furthermore, this evaluation would consolidate each WMO’s individual approach by anchoring it in the appropriate international Research, Design & Development (RD&D) context. Consequently, a multinational cooperation effort, allowing a transparent and effective information exchange between WMOs on post-closure criticality topics, will provide a great benefit. The paper gives an overview of the current efforts to establish and further develop such a WMO-level multinational collaboration. These efforts were recently initiated as a joint effort by Radioactive Waste Management Limited (RWM, UK) and the National Cooperative for the Disposal of Radioactive Waste (Nagra, Switzerland) in the context of the Implementing Geological Disposal of radioactive waste Technology Platform (IGD-TP) (<https://igdtp.eu>). The initiative presently enjoys great interest from more than ten WMOs from Europe, the U.S. and Canada. Further opportunities for wider involvement are encouraged and planned. The paper places this initiative in context by discussing previous international exchanges on post-closure criticality safety and by summarising their results and conclusions. Based on this, the motivation underpinning the present collaboration efforts are explained. Furthermore, the main goals and benefits envisioned for the collaborative work and the current status are presented. Lastly, the strategy and future plans for the proposed multinational cooperation are also summarised.

## INTRODUCTION

As spent nuclear fuel and radioactive waste contain fissile material, the demonstration of post-closure criticality safety (PCCS) is an important part of the safety case underpinning any deep geological radioactive waste disposal project. The work discussed here is focussed on spent fuel disposal, however, similar considerations apply to any high-level radioactive waste requiring disposal. While criticality safety assessments are performed routinely at various stages of the nuclear fuel cycle, for example during the elaboration of spent fuel loading plans for transport and intermediate storage casks, evaluating criticality safety in the post-closure phase raises specific challenges.

A significant challenge concerns the very long timescales, i.e. orders of magnitude larger than in any other area of the fuel cycle, over which the safety assessment is to be performed. Neither the IAEA requirements, formulated in the Specific Safety Requirements No. 5 of the IAEA Safety Standards Series [1], nor the associated recommendations, issued in IAEA SSG-27 [2] and IAEA SSG-14 [3], specify a particular timeframe for the assessment. However, this is typically defined by the regulatory bodies on the national level. For instance, the Swiss Federal Nuclear Safety Inspectorate (ENSI), indicates in the regulatory guideline G03 – “Specific Design Principles for Deep Geological Repositories and Requirements for the Safety Case” [4] that the time frame which must be considered for the safety analysis in the case of high-level radioactive waste (implicitly also for criticality safety) is *one million years* after repository closure. Similar timeframe requirements are formulated in other countries such as Sweden, through the regulatory code SSMFS 2008:37 [5] issued by the Swedish Radiation Safety Authority (SSM).

The starting-point for assessing criticality safety in the post-closure phase is the premise that all spent fuel canisters are in a subcritical state at the time of emplacement. In a timeframe of one million years, changes to the geological repository design or a potential degradation of the engineered and/or natural barriers may occur. Later in the assessment period, these modifications could lead to effects such as: a change in the geometry of the final disposal canister, bringing the fuel assemblies at a closer distance to each other; an increase in neutron moderation and/or reflection in the system; or a change in the composition and spatial distribution of the fissile material inside the fuel assemblies etc. These effects need to be considered in the criticality analysis to determine whether their occurrence could lead to a critical system and what the consequences of such a critical system on the disposal facility performance may be. Thus, the demonstration of criticality safety requires a high level of detail for the description of the system under consideration; otherwise, highly conservative assumptions have to be taken into account. In this context, the challenge lies in the elaboration and consideration of long-term nearfield evolution scenarios and understanding their impact on the corresponding evolution of the canister and spent fuel system.

Many WMO programmes foresee the disposal of spent nuclear fuel and, therefore, must address the regulatory task of assessing the post-closure criticality safety of their final disposal concept. The particular technical aspects as well as the degree of detail and the development stage of their disposal concept are clearly unique for each WMO. Nevertheless, many WMOs address similar aspects and challenges related to PCCS. Therefore, sharing of experience and knowledge between them would be beneficial to understand the similarities and differences in their approach and the reasons for this. This information exchange would also consolidate each individual approach by anchoring it in the appropriate international RD&D context.

In view of this, a WMO-level cooperation on post-closure criticality safety was proposed recently by the radioactive waste management organisations from the UK (RWM) and Switzerland (Nagra) under the umbrella of the IGD-TP. The paper provides an overview of the key aspects underpinning the envisioned collaboration and summarises its current status.

## previous information exchange on Pccs

There have been several WMO-level workshops on the topic of post-closure criticality safety previously. The first one took place in 2017, in Stockholm, Sweden, and was organised by the Swedish Nuclear Fuel and Waste Management Company (SKB). The subsequent WMO workshop was organised, in collaboration, by the UK’s Radioactive Waste Management organisation (RWM) and the Swiss National Cooperative for the Disposal of Radioactive Waste (Nagra) and took place in 2020 in Wettingen, Switzerland.

The two workshops were organised as independent meetings and were intended as an information exchange platform for the participating WMOs to provide updates and share their progress on a wide range of PCCS topics.

An important outcome of the two workshops was the understanding that there would be great benefit to expand the existing information exchange and further establish a regular, comprehensive and transparent communication between WMOs concerning applied methodologies, knowledge gaps and results and to collaborate in more detail on particular topics.

Since the second workshop in 2020, RWM and Nagra have continued their exchange on post-closure criticality safety aspects and consolidated further collaboration opportunities. However, it was concluded that there is maximum benefit in discussing contributions within a wider circle of participants. While several participating WMOs already had bilateral collaboration or information exchange agreements in place, a new multilateral information exchange and cooperation agreement would provide a significantly more suitable and appropriate framework. Such a multilateral exchange agreement on PCCS topics was proposed by RWM and Nagra in February 2021.

## the multilateral cooperation on post-closure criticality safety

The basic principles of the new multinational WMO-level cooperation proposed by RWM and Nagra, with a view to exchange information on PCCS, have been drafted and are summarised below. Thus, the main objectives envisioned for the cooperation have been formulated and an initial set of collaboration areas have been identified. Furthermore, concrete proposals concerning the implementation of the collaborative work have also been elaborated.

The envisioned WMO multilateral cooperation pursues no economic goals but aims solely at enabling an equitable information exchange between the participating WMOs, with the focus on scientific and technical information as well as results of research and development activities in the area of post-closure criticality safety.

As the issues are most pressing for WMOs and to avoid potential conflicts of interest, the cooperation foresees participation only from national waste management organisations and, wherever applicable, their external collaborators on PCCS matters, such as national research institutes, private sector contractors, etc, in first instance.

The main objectives envisioned for the collaboration are summarised in the next subsection.

### Cooperation Objectives

* Enable and stimulate the equitable sharing of information concerning post-closure criticality safety between cooperation participants, thus increasing awareness of their approaches and methodologies;
* Facilitate the equitable exchange of information concerning the participants’ progress on post-closure criticality safety work and related activities conducted internationally;
* Identify and enable the understanding of differences/similarities in the approaches of the participating WMOs, e.g. through reference case studies;
* Provide the appropriate framework to compare individual approaches and methodologies for demonstrating post-closure criticality safety and assess their corresponding advantages and/or mitigate any potential disadvantages;
* Enable the sharing of considerations and evidence that underpin scenarios and assumptions of common interest;
* Facilitate the validation of the participants’ methodologies by performing technical comparisons and reviews;
* Consolidate the technical understanding of the participants’ individual approaches while simultaneously following most up-to-date technical and scientific developments;
* Facilitate discussions on any apparent contradictions in the participants' individual lines of argumentation for the criticality safety assessment and understanding the reasons leading to the observed contradictions.
* Facilitate transparent communication such that any potential discrepancies between scientific results obtained by the participants can be analysed and understood, thus consolidating the technical basis of each WMO’s approach.
* Act as a mechanism to ensure that undertaking any work to address research needs that have multiple interested parties can be co-ordinated to achieve maximum benefit.

For the envisioned information exchange, five general areas of collaboration were agreed upon initially, as summarised in the following section. However, new topics may be proposed for consideration and added at a later stage, as progress is made on PCCS in general and the already established WMO information exchange is further consolidated.

### Areas of collaboration

#### WMO-level PCCS reference case

The parameters that each WMO takes into account for the criticality safety assessment (e.g. disposal canister design, fuel type, geology, etc.) vary between countries, in accordance to each individual disposal concept and spent fuel inventory. Nevertheless, comparing the different methodologies has clear benefits, such as, enabling a better understanding of each individual approach, allowing the assessment of potential advantages or disadvantages and placing individual RD&D efforts in the international context.

However, in the absence of a common set of parameters, carrying out a direct comparison and interpreting its results can be difficult. Consequently, it was proposed to develop a WMO-level reference case that consists of hypothetical scenario(s) and that participating WMOs could implement according to their own approach, with a view to allow direct comparison of results and methodologies.

#### Identification of radioactive waste record requirements

Radioactive waste data records, in particular for spent nuclear fuel, are needed for the post-closure criticality safety assessment. As inventories age, work is required to preserve the information in a systematic and consistent way. The aim of the cooperation is to discuss and identify the information required for PCCS and to review various strategies for obtaining, storing and managing this information.

As part of this activity, there is benefit in not only identifying all the information/data that should be available preferably, but also in establishing what is the minimum required for the criticality safety assessment.

#### PCCS scenario development

The timeframe to be considered in the post-closure criticality safety assessment spans over many thousands of years. Both probabilistic and deterministic PCCS approaches require a set of scenarios that describe: (*i*) the initial state of the nearfield and of the final disposal canister configuration, at the time of emplacement and (*ii*) their evolution with time. The scenario formulation typically aims for a realistic description of the system, bound by conservative assumptions to accommodate remaining parametric and conceptual uncertainties.

The cooperation in this area aims at understanding what scenarios have been selected for further PCCS analysis by the participating WMOs and the reasons that underpin that selection. Furthermore, collaborative work is envisioned to discuss feasible approaches to scenario formulation and selection and to carry out sensitivity studies based on selected scenarios.

#### Approach to taking burnup credit (BUC) in the PCCS assessment

In many cases, the irradiation history of the spent nuclear fuel must be taken into account to demonstrate the post-closure criticality safety of the final disposal canister configuration. Thus, taking burnup credit is an important part of criticality calculations in general and in the determination of loading curves in particular. The WMO cooperation in this field has several objectives such as:

* Discussing the general methodology for elaborating loading curves and individual (WMO-specific) implementations;
* Considering the relevant sources of uncertainty and sharing knowledge and experience concerning the methodology for uncertainty quantification;
* Reviewing approaches to address the determined uncertainties, e.g. by determining their impact on the loading curve determination;
* Assessing what data is necessary to demonstrate compliance with loading curves and how the compliance may be evaluated;
* Discussing the need to validate the software packages used in PCCS assessments and validation methodologies;
* Reviewing available post irradiation examination (PIE) data and other validation requirements to ensure the data is fit for purpose and appropriately reported;
* Considering methods to verify the BUC approach implementations with a view to avoid e.g. accidental misloadings of the final disposal canister.

#### Approach to criticality consequence assessment

While some national regulators require the demonstration of the fact that no criticality event can occur in the post-closure phase, others explicitly request an assessment of the potential consequences in the very unlikely case that criticality may occur. Due to the long timeframe considered in PCCS assessments, establishing the methodology to assess criticality consequences is challenging.

In this context, the envisioned WMO cooperation aims at enabling a better understanding of what type of analyses are being carried out and how they are implemented. Furthermore, the interpretation and communication of the results will also be discussed.

### Foreseen Implementation and Realisation

It was agreed that the envisioned information exchange on PCCS takes place as a continuous series of technical workshops in which each workshop is specifically dedicated to one of the topics described in section 3.2. Thus, each individual area of collaboration will be revisited and reviewed regularly, to ensure a good communication and understanding of the progress achieved in the meantime. In addition, a yearly general update workshop, envisioned to take place in person, is also proposed.

Wherever applicable and contingent on the topic of the exchange, it was agreed that the conclusions reached during the technical workshops could be summarised as state-of-knowledge documents or technical reports summarising the participants’ considerations, approach, progress status and results, etc. The envisioned documentation work represents a tangible output of the collaboration and also constitutes a referenceable source that may be used for future work.

### The IGD-TP Framework

The initial discussions regarding the multilateral WMO cooperation on post-closure criticality safety took place under the ***Implementing Geological Disposal of radioactive waste Technology Platform* (IGD-TP). The IGD-TP (**<https://igdtp.eu/>**) unites European WMOs and was launched in 2009. The IGD-TP vision aims at industrialisation of radioactive waste disposal by 2040 and is supported by a strategic research agenda that was published in 2020. Its executive group identified the further development of post-closure criticality safety assessment as a key priority.**

It was noted that many of the WMOs interested in participating in the proposed PCCS cooperation are already members of the IGD-TP. Furthermore, through its well established RD&D and information exchange programmes, the IGD-TP provides a suitable framework for elaborating and implementing the envisioned cooperation agreement. The framework comprises not only existing membership agreements between individual WMOs and the IGD-TP, which would facilitate their adherence to the multilateral cooperation on PCCS, but also a well established and easy to access information sharing platform which would promote the envisioned information exchange on PCCS.

## present status of the multilateral WMO cooperation on pccs

The multilateral WMO cooperation on post-closure criticality safety was proposed by the waste management organisations in the UK (RWM) and Switzerland (Nagra) in February 2021.

Subsequently, a preliminary discussion with other WMOs interested in the collaboration was organised in the form of an online workshop on the 22nd of March 2021. One of the main objectives of the workshop was to discuss and agree upon a suitable collaboration mechanism. It was decided that the IGD-TP *Project Agreement* framework represents the most appropriate and convenient collaboration mechanism.

A preliminary version of the envisioned IGD-TP project agreement was elaborated by Nagra with input from the IGD-TP Executive Group and RWM. The agreement is presently under final review and awaits the final approval and signature from the participating WMOs.

Presently, nine additional national waste management organisations have expressed their interest in participating in the multilateral cooperation on PCCS proposed by RWM and Nagra. The possibility that other interested WMOs may join the project agreement at a later stage was also taken into account. An overview is given in Table 1.

TABLE 1. WMOs EXPRESSING INTEREST IN THE MULTILATERAL COOPERATION ON PCCS

|  |  |
| --- | --- |
| Country | WMO |
| Belgium | ONDRAF/NIRAS |
| Canada | NWMO |
| Finland | Posiva/TVO |
| France | ANDRA |
| Germany | BGE and GRS |
| Hungary | PURAM |
| Spain | ENRESA |
| Sweden | SKB |
| Switzerland | Nagra |
| U.K. | RWM |
| U.S. | DOE\* |
| \*Represented by Pacific Northwest National   Laboratory and Sandia National Laboratories | |

Presently, three technical workshops have been organised in the form of online meetings. The workshops deliberately focussed on general topics that did not explicitly require the IGD-TP project agreement to be in force. The PCCS areas discussed during the workshops include: the elaboration of a WMO-level PCCS reference case to enable comparisons and validations between individual methodologies and approaches and the identification of spent fuel data records required for carrying out the criticality safety assessment for the post-closure phase.

## summary and outlook

Carrying out the criticality safety assessment of a geological final disposal concept in the post-closure phase is a regulatory requirement that many waste management organisations must fulfil. The long timeframe to be considered in the assessment raises specific technical and scientific challenges. It was recognised that, while certain aspects are intrinsically related to the particularities of each individual disposal concept, the WMOs do, in fact, address many similar challenges. Thus, a WMO-level multilateral cooperation agreement, enabling an equitable information exchange on post-closure criticality safety aspects, provides clear benefits. Such a collaboration was proposed and formulated under the IGD-TP framework by RWM and Nagra.

The paper presented the envisioned objectives of the cooperation, its initial scope and the proposed means of implementation. The IGD-TP project agreement on PCCS, i.e. the framework enabling the multilateral WMO cooperation, has been formulated and it is presently awaiting the final approval of the participating waste management organisations. The already initiated WMO information exchange will progress in the form of a continues series of technical workshops, documented as technical reports and state-of-knowledge documents. The entry in force of the IGD-TP project agreement will consolidate the already established good communication between the participating WMOs and will further facilitate progress on a wide set of PCCS technical and RD&D topics.

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