European Joint Programme
on Radioactive Waste Management

MOBILITY MISSION REPORT

This work has been partially supported by the EURAD project that has received funding from H2020-EURATOM 1.2 under grant agreement ID 847593.

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MISSION TITLE

Assessment of FRAPCON-xt and BISON codes to predict fuel performance in Dry Storage

DESCRIPTION

Concerned organisations

- Research entities (CIEMAT – VTT)

Concerned infrastructures or facilities

- High-performance computing

Concerned phases

PHASE 1: Software installation and familiarization with the tools to be used (Trelis, MOOSE, BISON and Paraview)

PHASE 2: Development of the input decks for the rods selected based on the inputs given by the developers.

PHASE 3: Code execution

PHASE 4: Results assessment and comparison with those given by FRAPCON-xt

PHASE 5: Reporting

Themes and topics

Theme 7: Performance assessment, safety case development, and safety analyses

- Integration of safety-related information
- Performance assessment and system models
- Treatment of uncertainties

Keywords

DRY STORAGE, FUEL PERFORMANCE CODES, HYDRIDES, ROD INTERNAL PRESSURES

EXECUTIVE SUMMARY

One of the objectives of EURAD WP8 is to study the spent nuclear fuel (SNF) behaviour under accident conditions, which may lead to a potential loss of confinement during storage, transport and predisposal activities.

For a proper study of this behaviour, an accurate initial characterization of this SNF is of utmost importance. Rod Internal Pressures (RIP) reached by the rods during their life in reactor have a great impact on the reorientation of the hydrides during dry storage, this reorientation may lead to a fragilization of the cladding.

Fuel Performance Codes (FPC) are used to characterize the fuel rods at end-of-life (EOL) in reactor.

The main objective of the mission consisted in compare two well-known FPCs in terms of the initial characterization of the SNF, the variables studied were those which have an impact on the reorientation of the hydrides in the dry storage stage (internal pressures, cladding oxide thickness and cladding hydrogen content and radial distribution). The FPCs compared were an extension made in CIEMAT of the FPC FRAPCON (i.e. FRAPCON-xt) and BISON.

1. MISSION BACKGROUND

1.1. R&D background

During the interim storage of the spent nuclear fuel in dry conditions, before its final disposal, this fuel can be submitted to different phenomena which could lead to the degradation of its thermo-mechanical properties. The evolution of these degrading mechanisms strongly depends on the initial state of the spent fuel. The initial characterization of the spent fuel is, therefore, an essential step in the development of a methodology for the assessment of accident scenarios during dry storage and transportation of the spent fuel. The spent nuclear fuel is stored in dry conditions several tens of years without any kind of thermo-mechanical inspection so, fuel performance codes extended to dry storage, play an important role in predicting how this fuel behaves during this stage. In order to have good predictions of this behaviour, these codes should be fed with an accurate initial state of the spent nuclear fuel.

1.2. Mission objectives

The main objective of the internship is to assess and improve the predictive capability of the thermo-mechanical fuel performance code FRAPCON-xt for its application to spent fuel dry storage within the EURAD's WP8 framework.

Two main activities have been proposed:

- FRAPCON-xt – BISON comparison in terms of characterization of spent nuclear fuel at the beginning of the Dry Storage stage. A database based on open literature is to be built for this comparison, with special emphasis on high burnup fuels that have been thoroughly characterized at the end of life through post-irradiation examinations and whose in-reactor power histories are available. Once the fuel initial characterization for dry storage is well defined, an assessment of the predictive capacities of the codes during this stage would be made.

- From the comparison set in the previous activity, a thorough rationale of differences between both tools will support the deep analysis of FRAPCON-xt and identification of the potential enhancements that would benefit the code's current predictability.

Additionally, due to the broad experience of VTT in uncertainty quantification and sensitivity analysis applied to fuel performance, this internship can be also useful to improve our methodology for failure rod quantification.

1.3. Mission request

1.4. Mission composition

Host organisation

VTT Technical Research Centre of Finland Ltd

Host facility

VTT Centre for Nuclear Safety

Mission dates

1 April 2022 – 30 June 2022

2. MAJOR PRACTICES, TECHNIQUES, METHODS, TOOLS OR SYSTEMS OPERATED OR STUDIED

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2.1. Practice, technique, method, tool or system operated or studied during the mission

BISON – A Finite Element-Based Nuclear Fuel Performance Code.

Description

BISON is a finite element-based nuclear fuel performance code applicable to a variety of fuel forms including light water reactor fuel rods, TRISO particle fuel, and metallic rod and plate fuel. It is a multiphysics fuel analysis tool that solves fully-coupled thermomechanical problems.

Usage

Input creation: A simplified smeared pellet model was used for the meshing.

Code execution: The code was executed both in VTT's cluster and on a local computer.

Post-processing: The results obtained were visualized with the Paraview software and exported to a csv file.

Benefits

BISON, as a fully coupled thermo-mechanics code with 1D, 2D-RZ & 3D capabilities, allows a more detailed analysis than FRAPCON, by comparing both codes between themselves and also with experimental data the intention is to find possible improvements in the modelization of FRAPCON-xt in order to obtain more accurate results in the initial characterization of the thermo-mechanical properties of the spent fuel and in the evolution of these properties along the storage stage.

Limitations

The smeared pellet geometry, chosen to perform this study, simplifies the pellets to cylinders and does not take into account either the dishes or chamfers.

Applicability

Despite having some problems with the license acquisition, it is planned to instal the code in CIEMAT in the following months.

2.2. Practice, technique, method, tool or system operated or studied during the mission

FRAPCON-xt

Description

FRAPCON-xt is the CIEMAT's extension of the steady-state fuel performance code FRAPCON (PNNL) to dry storage conditions. The modelling carried out to extend the code encompasses mechanisms such as cladding creep and hydrogen transport and precipitation within the cladding.

Usage

In the case of hydrogen precipitation within the cladding, an external model, coupled with FRAPCON-xt and also developed by CIEMAT, called HYDCLAD, was used.

Benefits

The code extends FRAPCON's capabilities to simulate the evolution of the spent nuclear fuel during the dry storage.

Limitations

Despite FRAPCON-xt, coupled with HYDCLAD, takes into account the distribution and precipitation of the hydrogen within the cladding, the radial reorientation of the precipitated hydrides is not implemented yet.

Applicability

FRAPCON-xt was developed in CIEMAT, so it is already implemented in my home context.

2.3. Practice, technique, method, tool or system operated or studied during the mission

Description

Usage

Benefits

Limitations

Applicability

2.4. Practice, technique, method, tool or system operated or studied during the mission

Description

Usage

Benefits

Limitations

Applicability

3. MISSION FINDINGS AND CONCLUSIONS

3.1. Lessons learned and conclusions

Some insights have been obtained from this secondment, the main conclusions can be resumed in the next bullets:

- In the case of the fission gas releases predictions, the estimations made with BISON does not improve those obtained with FRAPCON.
- Regarding the estimations of free void volume within the fuel rods, BISON seems to make better predictions of the evolution of the void volume with the burnup. This phenomena is not fully understood yet but may be something to implement in FRAPCON-xt in order to enhance its predictions of the rod internal pressures.
- Similar results for the cladding hydrogen radial profiles was obtained as they are both based in the same model.

3.2. Relevant findings and conclusions for home organisation

Some improvements in FRAPCON's void volume predictions could be implemented based on BISON modelling to enhance the accuracy of the rod internal pressures estimations.

Despite having a simpler architecture, the code HYDCLAD gives similar results of the distribution of the hydrogen in the cladding radial direction.

Despite the difficulties of the liscence adquisition process it may be useful to obtain BISON code for future studies.

3.3. Relevant findings and conclusions for host organisation

3.4. Relevant findings and conclusions for other organisations

4. POTENTIALS FOR IMPROVEMENT OR DEVELOPMENT

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4.1. Generic potentials

4.2. Potentials for home organisation

4.3. Potentials for host organisation

APPENDICES

Mission journal

WEEK 1-2: Installation of the software needed (Trelis, FRAPCON-xt, Paraview...). CIEMAT's liscence for the code BISON wont be available until week 9.

WEEK 3-4: Reading BISON documentation (Workshop, manual, ...)

WEEK 5-8: Simulation of 4 fuel rods (Calvert Cliffs-1) for the comparation of the codes in terms of rod internal pressures (FGR and Void Volumes)

WEEK 9: Installation of the code BISON in a local machine.

WEEK 10-13: Simulation of the A06 rod. Hidrogen distribution analysis.

Mission bibliography

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REPORT APPROVAL

Date	Beneficiary	Home mentor/supervisor	Host mentor/supervisor
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	Visa	Visa	Visa