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Status Report on Activities of the Systems Assessment Task Force, OECD-NEA Expert Group on Accident Tolerant Fuels for LWRs

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1. INTRODUCTION

The Organization for Economic Cooperation and Development /Nuclear Energy Agency (OECD/NEA) Nuclear Science Committee approved the formation of an Expert Group on Accident Tolerant Fuel (ATF) for LWRs (EGATFL) in 2014. Chaired by Kemal Pasamehmetoglu, INL Associate Laboratory Director for Nuclear Science and Technology, the mandate for the EGATFL defines work under three task forces: (1) Systems Assessment, (2) Cladding and Core Materials, and (3) Fuel Concepts. Scope for the Systems Assessment task force (TF1) includes definition of evaluation metrics for ATF, technology readiness level definition, definition of illustrative scenarios for ATF evaluation, and identification of fuel performance and system codes applicable to ATF evaluation. The Cladding and Core Materials (TF2) and Fuel Concepts (TF3) task forces will identify gaps and needs for modeling and experimental demonstration; define key properties of interest; identify the data necessary to perform concept evaluation under normal conditions and illustrative scenarios; identify available infrastructure (internationally) to support experimental needs; and make recommendations on priorities. Where possible, considering proprietary and other export restrictions (e.g., International Traffic in Arms Regulations), the Expert Group will facilitate the sharing of data and lessons learned across the international group membership. The Systems Assessment task force is chaired by Shannon Bragg-Sitton (Idaho National Laboratory [INL], U.S.), the Cladding Task Force is chaired by Marie Moatti (Electricite de France [EdF], France), and the Fuels Task Force is chaired by a Masaki Kurata (Japan Atomic Energy Agency [JAEA], Japan). The original Expert Group mandate was established for June 2014 to June 2016. In April 2016 the Expert Group voted to extend the mandate one additional year to June 2017 in order to complete the task force deliverables; this request was subsequently approved by the Nuclear Science Committee. This report provides an update on the status Systems Assessment Task Force activities.

2. SYSTEMS ASSESSMENT TASK FORCE SCOPE

Scope for the EGATF Systems Assessment task force includes definition of evaluation metrics for ATF, technology readiness level definition, definition of illustrative scenarios for ATF evaluation, and identification of applicable fuel performance and system codes. The initial Task Force scope also included potential to perform parametric assessments of fuel performance to determine the most impactful parameters/properties on the fuel system performance and behviors. Sub-tasks have been grouped to manage the amount of work and to provide clear deliverables. The Systems Assessment task force originally planned to deliver two reports:

1. Evaluation Metrics and Technology Readiness Level Definition
2. ATF Evaluation – Selected Illustrative Scenarios, Applicable Codes and Parametric Studies

However, upon compilation of the information for the two reports it was decided that these efforts would be combined into a single deliverable report. Parametric studies will not be included in the final deliverable, although recommendations for sensitivity studies will be made. The final deliverable will be completed in Fall 2016 and will be submitted to NEA for review such that it can be issued prior to June 2017.

The Systems Assessment Task Force report will compile an agreed set of evaluation metrics (including recommended evaluation tests) for ATF fuel and cladding; definition of technology readiness levels as they relate to fuel systems; definition of illustrative scenarios for both PWRs and BWRs that will be used by each member organization to the expert group to ensure that evaluation results (performance trends) can be compared across multiple organizations; and a summary of available fuel performance and codes that can be used to evaluate ATF performance, can be modified to evaluate ATF concepts, or are under development.

2.1 Evaluation Metrics

The ATF performance metrics and evaluation approach proposed within the U.S. were presented at the September 2014 EGATFL meeting as a starting point for an international set of ATF performance and evaluation metrics. This approach is documented in detail in FCRD-FUEL-2013-000264 (INL/EXT-13-29957). Additionally, proposed metrics for France and Japan are being incorporated to develop the international document, with consensus achieved among all countries/organizations represented on the Task Force. The proposed evaluation metrics for the U.S. are available in summary form in Bragg-Sitton et al. (2016).[1] This journal article additionally covers proposed weighting of different performance aspects considered in the technical evaluation. These weighting factors were developed with the assistance of the Industry Advisory Committee and were reviewed by the Independent Review Committee established for ATF prioritization.

It is clear in all discussions on ATF that all countries/organizations developing ATF seek to extend the fuel system "coping time" under severe accident conditions. However, it is not clear how much additional coping time is desired, nor is it clear how coping time is being defined by each organization. A key decision taken in the April 2016 EGATFL Task Force 1 meeting was to clearly define "coping time" for use in NEA evaluations of ATF performance. At the April 2016 meeting, it was agreed that ATF concepts will be evaluated based on their ability to increase the "fuel coping time" under severe accident scenarios, where coping time is defined as follows:

> **Fuel Coping Time:**
> The time to significant loss of geometry of the fuel assemblies such that the reactor core can no longer be cooled or the fuel cannot be removed from the reactor using standard tools and procedures.

It was noted that each fuel system concept should have an associated failure modes and effects analysis conducted to determine the onset of failure modes that would lead to unacceptable conditions or performance. Additionally, the appropriate time may correspond to the point at which the condition is not recoverable. This is sometimes referred to as an "escalation point;" e.g. a point at which the addition of water to the vessel can no longer provide sufficient cooling to halt the accident progression or could make the situation worse.

2.2 Technology Readiness Level

Definition of technology readiness levels (TRLs) for fuel and cladding were presented at the March 2015 EGATFL meeting by representatives from the U.S., the U.K., and Japan; the TRL definition report issued by the NEA Expert Group on Innovative Fuels was also summarized. The Working Party on Fuel Cycle (WPFC) Expert Group on Innovative Fuels issued a definition of Technology Readiness Level (TRL) applicable to fuels for transmutation purposes. This information is included in the state-of-the-art

[1] **Bragg-Sitton, S.M.,** Todosow, M., Montgomery, R., Stanek, C.R., Montgomery, R., and Carmack, W.J., Metrics for the Technical Performance Evaluation of Light Water Reactor Accident Tolerant Fuel, *Nuclear Technology*, 195(2), p. 111-123, August 2016.

report published in 2014 (available at this link https://www.oecd-nea.org/science/pubs/2014/6895-report-innovative-fuels.pdf). The specificity of the analysis carried out by the Innovative Fuels Expert Group was to take into account all possible combinations for fabrication (materials quality, materials quantity) and in-pile performance (test environment, test size), leading to a quite complete characterisation of possible levels of maturity. Members of the EGATFL Systems Assessment Task Force agreed to make minor adaptations to the TRL definition elaborated by the Innovative Fuels Expert Group such that it is fully applicable to ATF candidates. This section of the task force report is nearing completion.

2.3 Definition of Illustrative Scenarios

Two key illustrative scenarios are proposed for application to general water-cooled reactor concepts. These scenarios are identified to bound the range of severe accidents, and they are intended to not be overly prescriptive or specific to a particular facility design. Modeling of these scenarios should utilize the appropriate initiating event, then allowed to carry through to the point of core failure. General agreement was reached among the international community on two scenarios applicable to general reactor designs:

1) **Station Blackout (SBO):** High pressure scenario; evaluation taken to the point of reactor pressure vessel failure

2) **Large-break LOCA (LBLOCA):** Low pressure scenario (high decay heat at loss of coolant)

Simulation of these scenarios should be conducted using an appropriate PWR, BWR, or VVER model, as appropriate to the country conducting the evaluation. Illustrative scenarios should be considered standard scenarios for the comparison of a candidate ATF concept to the standard Zr-UO_2 fuel system that is currently employed (using the appropriate alloys, enrichment, etc. for the reactor type being simulated) and for comparison of multiple ATF concepts to one another.

The proposed scenarios are intended to provide bounding cases for fuel performance. It is expected that each country or development team will utilize fuel performance and system analysis codes that are accepted within the associated organization to conduct these evaluations. All ATF evaluations under the selected accident conditions should be allowed to progress to the point of core failure in the analysis. This allows one to estimate the potential increase in coping time that might be offered by candidate ATF concepts and to assess potential outcomes should failure occur (e.g. if the fuel fails, how does it fail?). Pressure is a very significant parameter in the accident progression, as reflected in the selection of both a high-pressure and low-pressure scenario. Following completion of bounding analyses, it is recommended that researchers perform parametric studies for these illustrative scenarios to develop a better understanding of the impact of additional variables. Such parametric studies could include variation of the point in the operating cycle that the accident occurs (e.g., how much burnup has been accumulated in the fuel?) and the time after reactor scram that core cooling is lost.

2.4 Fuel Performance and System Codes

Fuel performance and system codes that can be used to evaluate accident tolerant fuel performance, can be modified to evaluate ATF concepts, or are under development. Current limitations of the identified codes and data required to run these codes should be identified, and availability of the identified codes to other organizations or countries should be clarified.

Standard evaluation of ATF concepts includes neutronics, thermal-hydraulic analyses, fuel performance, and detailed systems analyses. A standard suite of tools typically is used for initial screening analyses, including infinite lattice calculations to estimate basic concept feasibility and three-dimensional core analysis to assess thermal hydraulics, temperature feedback, etc. Work is currently being conducted in the U.S. to develop advanced modelling and simulation tools and to incorporate ATF properties and behavioural characteristics. Additionally, existing severe accident analysis tools are being modified to incorporate ATF characteristics. Although some of the tools are limited in fidelity, particularly with regard to ATF concepts for which little property and behavioural data is available, they do provide initial estimates of performance for these concepts.

Discussion among the task force participants has identified additional codes that are being utilized outside of the U.S. Department of Energy research program. Many of these tools are limited in their application to ATF concepts at this time, but additional data that will be made available from ongoing research programs will significantly enhance these capabilities. In many cases companies and organizations select their own internal tools to perform fuel performance, system, and severe accident analyses. The overall trends observed for materials using these different codes should be studied; the EGATFL task force activities will not attempt to benchmark codes against one another.

3. SUMMARY

This report provides a brief update on the activities conducted within the Systems Assessment task force (TF1) for the OECD/NEA Expert Group on Accident Tolerant Fuels for LWRs. Note that the remaining task forces within the EGATFL on Cladding and Core Materials (TF2) and Fuel Concepts (TF3) will each produce a state-of-the-art report on the materials under development across the NEA member countries and involved observer countries (e.g. China). These state-of-the-art reports are targeted for completion in ~June 2017.

Appendix A

Outline of Deliverable Report

Assessment of Light Water Reactor Accident Tolerant Fuel: Evaluation Metrics and Illustrative Scenarios

6. DEFINITION OF ILLUSTRATIVE SCENARIOS FOR EVLUATION

6.1. High Pressure Scenario: Station Blackout

6.2. Low Pressure Scenario: Large Break Loss of Coolant Accident

7. APPLICABLE CODES FOR FUEL PERFORMANCE EVALUATION

7.1. Standard Screening Analyses for ATF Concepts

7.2. Advanced Fuel Performance Modeling Tools

7.3. Severe Accident Analysis

8. REFERENCES