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THE QUALIFICATION PROCESSES OF SIMULATION TOOLS, COMPONENTS AND SYSTEMS WITHIN THE FRAMEWORK OF THE ASTRID PROJECT – DESCRIPTION AND EXAMPLES

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ASTRID is the Advanced Sodium Technological Reactor for Industrial Demonstration which is intended to be a Generation IV prototype reactor, with substantial strong improvements in safety and operability. In order to meet the objectives of the 4th generation reactors and comply with the related specifications, the ASTRID project integrates innovative options.

From the beginning, the project took into account the qualification actions related to these choices and initiated the qualification program of the ASTRID Sodium Fast Reactor. The objectives were to collect needs expressed by different Technological Working Groups involved in ASTRID and to organize then the further treatment of the needs. A risk evaluation was also performed through an evaluation of the maturity level of the technical options using a Technological Readiness Level process (TRL ranking table).

The objective at the current stage of the project is to pursue this process and to supplement the approach by extending it to the entire ASTRID breakdown product structure in order to take into account the interfaces and the integration of the elementary systems. This paper presents the technical qualification method selected to homogenize the approach in the different fields of the ASTRID project.

The simulation tools which are very important to obtain confidence in the feasibility of the proposed innovations and to support the safety files must also follow a qualification process. This process, similar to that related to equipments and systems, is described.

Some examples are given to underline the importance of the different mock-ups used during the qualification processes.

I. INTRODUCTION

The ASTRID reactor is a technological demonstrator designed by the CEA together with its industrial partners, subjected to a very high level of requirements.

Innovative options have been introduced in the design to enhance safety and to take into account the lessons learnt from the Fukushima accident. These options enhance safety, improve reliability and operability and make the Generation IV SFR an attractive option for electricity production and fuel cycle management.

Consequently, these technological options combined with the new safety features are leading to new needs in terms of qualification, demonstration of the relevance of the proposed safety options, efficiency and robustness of the concepts.

The selection process of the design options and the safety studies of the ASTRID reactor also rely on the use of scientific computing tools, some of which need new functionalities to fully address the needs and particularities of this new reactor. These simulation tools need to be qualified for their use in the ASTRID studies.

Finally, the technological features as well as the simulation tools have to comply with a rigorous approach of qualification in order to meet the requirements of the French Regulation. It also has to comply with the schedule and the different milestones of the project.

This paper is going to describe the qualification process the components and the systems must comply with and the one to be followed by the simulation tools. The links and the similarities between the two qualification processes will be underlined. Some examples will be given to point out the importance of the different mock-ups used in the qualification processes.

II. DESCRIPTION OF THE PROCESSES

II.A. Component and system qualification process

In every major and complex project principally driven by innovation, the perspective of R&D needs and Qualification program is a matter of concern. As a consequence, it is essential to anticipate, as early as possible, these needs and to implement a qualification methodology.

During the Conceptual Design phase (named AVP2 phase, from 2013 till the end of 2015) the evaluation of the qualification program of the ASTRID Sodium Fast Reactor was initiated and a methodology was defined¹. It consisted in collecting the exhaustive list of R&D needs and technological demonstration tests to be fulfilled on representative mock-ups before introducing the concept in the prototype. It has also been presented how this compilation of needs was managed, evaluated and prioritized in terms of Project Risk Management by means of a Technological Readiness Level grid (TRL).

In line with the work already accomplished, the implementation of the qualification process is presented. It defines the terminology to be adopted to standardize and facilitate relationships within the project. It also describes the different steps to be followed to perform a system or a component qualification.

II.A.1. General Information

The objective at this stage of the project is to deal with the qualification from the design to the development of the product, which is the technological qualification.

The purpose of the qualification is to produce a qualification file, demonstrating that the equipment complies with the required performances and safety options. The qualification process must be coherent with the evolution of the project throughout its progress. The main steps of the qualification process can be represented as a V cycle as shown in figure 1.

These steps are going to be detailed hereafter.

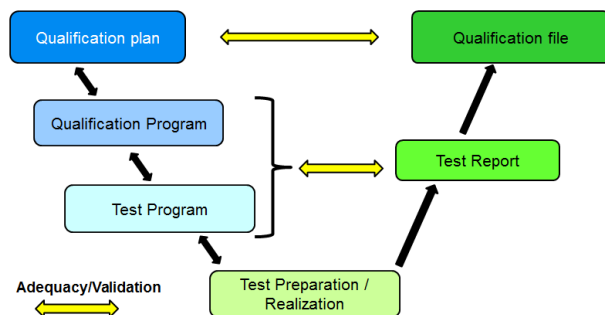


Fig. 1: Main steps of the qualification process - V cycle.

II.A.2. Qualification Plan

An important inventory work must be done on the basis of the ASTRID product breakdown structure and the functional breakdown structure. The goal of this work is to determine which equipment or system must be qualified and what will be the subjects of the qualification (performances, lifetime, production method, sizing...).

It's important to take into account the interfaces and the integration of the elementary systems. To do so, methodologies of evaluation of the degree of maturity can be used. These methodologies contribute to perform an exhaustive analysis of the notion of qualification. Beyond the Technology Readiness Level (TRL), the Integration Readiness Level (IRL) has been introduced to address some of the limitations associated with the original development of the TRLs². The IRL is used to evaluate the integration readiness of any two TRL-assessed technologies. The System Readiness Levels (SRL) and the Manufacturing Readiness Levels (MRL) can also be useful in order to evaluate these aspects of the qualification.

The establishment of a strategy is also a key point because experimental tests are expensive. There are three kinds of qualification:

- The one based on analysis consists in demonstrating by a qualitative and/or quantitative reasoning that the product can fulfill his function(s). The method by analysis is often based on considerations of analogy between equipment and involves the use of simulation tools.
- The qualification can of course also be done with tests.
- Finally, the qualification can be a combination of test and analysis.

At the end of this stage, the qualification plan must be provided. This document synthesizes the work done, describes and justifies the strategy chosen to drive the qualification.

II.A.3. Qualification Program

The qualification program puts forward a more precise definition of the tasks identified in the qualification plan. It defines the type of tests which must be made and the associated schedule in collaboration with the concerned facilities. The qualification tests have to demonstrate that the equipment or system can work in its specified environment.

If tests are performed on mock-ups, the proof of transposition of the test to the considered case must be provided.

II.A.4. Test Program

The test program can then be detailed. It often implies numerous exchanges with the facilities in which the tests are planned to be realized. It describes more precisely than the qualification program the tests to be done.

II.A.5. Test Preparation and Realization

This phase corresponds to the realization of a mock-up, a prototype, the realization of an experimental device, the modification of a facility...Generally this phase has been launched in parallel to the establishment of the qualification program.

The tests are then performed according to the test protocol developed on the basis of the test program.

II.A.6. Test Report

The test report has to supply all the data allowing the interpretation and the exploitation of the tests. It has to meet the requirements of the qualification and test programs.

II.A.6. Qualification File

To finish, the qualification file must be provided. This file has to demonstrate that the domain of the performed tests is in adequacy with the required qualification domain. It must demonstrate the qualification of the equipment and /or system with regards to its qualification plan. If it has not been done before and if tests have been performed on mock-ups, it must provide the proof of the transposition of the test to the considered case.

On the basis of the qualification file, the equipment or system can then be considered as qualified. The qualification file establishes the proof of the capacity of the equipment or system.

II.B. Simulation Tools Qualification Process

The French Regulation for Basic Nuclear Installations, issued in 2012, requires the safety demonstration to rely on calculation tools which are qualified for the domains they are used in.

The Qualification level for a calculation tool is the final level which has to be performed after the well-known VVUQ (Verification, Validation and Uncertainties Quantification) process. This level is achieved at the end of a long-term process³ which involves several steps, briefly described hereafter.

Subsequent to the Development, the **Verification** step ensures that the resolution of the equations is correct. In other words, it must be ensured that the calculation tool works as expected (correct digital implementation, correct numerical solution).

Then, the **Validation** of a scientific calculation tool is the process of assessing its predictive ability of real

phenomena with regard to the use in the targeted field. It aims to achieve the quantification of uncertainties associated with the calculated quantities.

The validation is to ensure that the mathematical model developed for the calculation of physical phenomena has the ability to represent them properly in an identified domain.

The validation is led according to the validation plan which must have been established previously and the content of which is represented in figure 2. The validation plan describes the strategy of the validation. The validation phase consists in comparing the results of the simulation tool to experimental data coming from mock-ups and/or reactor operation feedback, as well as to already qualified calculations (benchmarking). This might be called the analysis part of the validation plan.

The ASTRID simulation tools benefit from a vast experimental data base, relying on the feedback from numerous tests, particularly in the PHENIX and SUPERPHENIX reactors. Nevertheless, the innovative design options of ASTRID involve new needs in terms of R&D programs and motivate the development of new test facilities. Considering the considerable cost of these experiments and the need to widen the set of relevant experiments, international collaboration is required. These new testing needs are gathered in the experimental plan which is thus another part of the validation plan.

To be complete the validation plan must also deal with costs, risks and schedule.

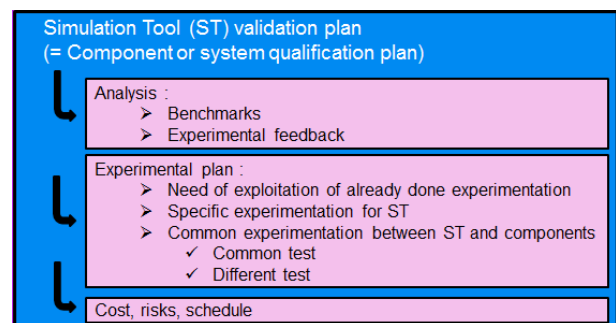


Fig. 2: Content of the validation plan.

Finally, the **Qualification** step is the last stage of the process. The goals of this step are to ensure the validity and the relevance of the obtained results, as well as to demonstrate the quality and the confidence in the provided results. This step must be done by the calculation tool user.

During this step, it must be ensured that the field of use of the tool in the future study is consistent with its validation domain. The tool must be used in the domain where it is supposed to be valid and the proof of this verification must be provided.

The transposition to reactor case, which involves checking the ability of the scientific calculation tool to simulate reactor conditions, must also be provided. This transposition must also include the quantification of the associated uncertainties.

The representation shown in figure 3 can be an efficient tool to assess the relevance of use of the simulation tool by focusing on the overlapping of the application and validation domains. Of course, this representation needs the identification of the influential parameters (called A, B, C...) on the major physical phenomena simulated with the calculation tool.

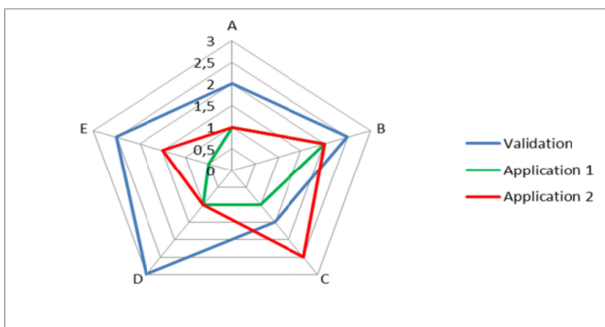


Fig. 3: Representations of validation and application domains.

Every user of a simulation tool must be able to justify and demonstrate the compliance to the approach through the formalization of this step which is a key point in accepting studies dedicated to the safety demonstration.

The above described approach must be followed by all ASTRID partners in order to provide valid safety files, such as required by the French Safety Authorities.

II.C. Interaction between the two previous processes

The components and systems qualification process and the simulation tools qualification process follow the same approach and are tightly linked. In both cases it must be demonstrated that the equipment or the tool can be used with confidence and will fulfill the required performances.

The validation plan of a simulation tool is equivalent to the qualification plan for equipment or a system. They both describe the strategy chosen which will lead to the qualification.

Furthermore, as represented in figure 4, the analysis part of the qualification can require the use of a simulation tool which has to be qualified for the concerned use. The qualification of a tool relies on its validation built with the realization of experimentation

which can be shared with the experimentation required for equipment qualification.

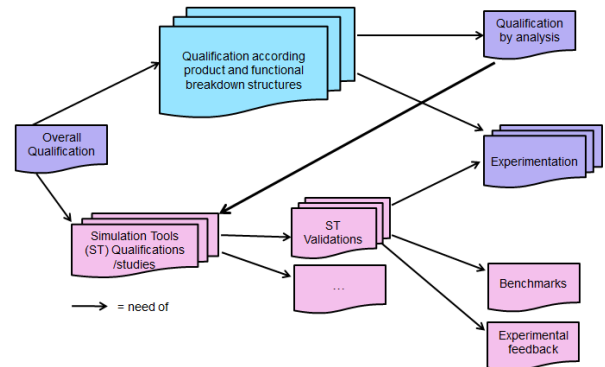


Fig. 4: Links between simulation tool qualification and components and systems qualification.

III. EXAMPLES

As it has been described before, the experimentation can be performed for components and systems or for simulation tools or can also be useful for both of these needs. Some examples are going to be given to underline the importance of the different mock-ups used during the qualification processes.

Of course, as it was described in section II, the examples which are going to be given are only a part of the qualification process.

III.A. THE SODIUM GAS HEAT EXCHANGER

III.A.1. Introduction

The study of an ASTRID option with gas Power Conversion System (PCS) is leading to an important R&D and design program work which is extensively described in related papers^{4,5}. In the gas PCS, one of the key components is the Sodium / Gas Heat Exchanger (SGHE), allowing to transfer a total heat power of 1500 MWth between the 4 secondary sodium loops and the 8 gas loops of the power conversion system.

The principle of the design is to put Compact Plate Heat Exchanger (CPHE) modules in a pressurized vessel playing also a header function (figure 5). The main motivations of this design are: (i) the bundle of plates is in compression (this limits the tensile solicitations in the structure), (ii) there is a limitation of constraints due to hyperstatism (each module is free to thermal expansion), (iii) the pressure drop on the gas side is minimized, (vessel acting as header), (iv) access to the module access is allowed for maintenance and inspection, (v) there are two confinement barriers between the sodium and the heat exchanger building environment (hence a module failure

has no impact on the outside), (vi) the Na inventory is low ($<8\text{m}^3$).

The manufacturing process foreseen for the CPHE is based on diffusion bonding by hot isostatic pressing (DB-HIP), but with specific procedure allowing 100 % manufacturing control.

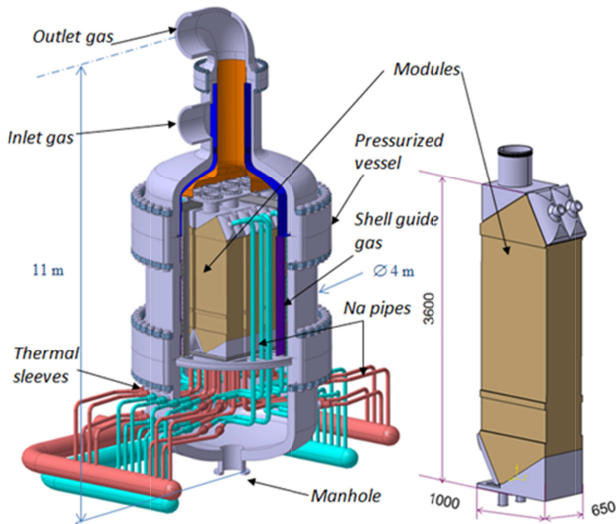


Fig. 5: SGHE design layout.

No CPHE has never been industrially manufactured in SGHE dimensions (fig.5), nor has been used with sodium. A large development and qualification program has been launched, in order to qualify thermal hydraulic performances, the design based on narrow channels and its compatibility with Na (draining, cleaning, potential self-plugging), thermomechanical analyses to justify the design, manufacturing process definition, material characterization, standards and rules update, ...

III.A.2. R&D needs in SGHE qualification

The development of this SGHE may be broken down into three main stages:

1. Conceptual studies and related justification calculations: this stage has to provide a certain number of innovations and related patents relative to (i) the design of the component itself, (ii) the manufacturing process, (iii) the exchange pattern allowing an improved thermal compactness, (iv) the Na collectors to ensure a homogeneous distribution of the modules. These studies strongly rely on theoretical works, partially validated.

2. Analytical validation where the objective is the experimental validation on a reduced scale with simulating fluid, on representative parts of the concepts and models proposed and / or developed in the previous stage. For the thermal hydraulic performance studies, the

validations were carried out on the scale of the gas-side channel⁵ (test sections implementing LASER viewing), Na headers by means of water-to-sodium similarity tests at channel scale and scale 1 on DANAH facility (fig.6).

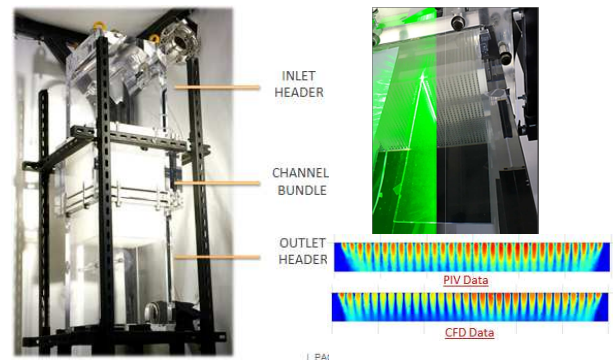


Fig. 6: DANAH facility. Illustration showing calculated and measured channels outlet velocity profiles.

3. Global qualification: the objective is to take into account in a same test all the significant parameters validated individually in the previous stages. For that, it is needed a functional heat exchanger mock-up working with ASTRID conditions. In order to limit the risk and associated costs, two qualifications scales were chosen:

- Small scale: tests on elementary Heat eXchanger (HX) mock-ups with a heat power capacity up to 40 kW. These tests are performed in the DIADEMO facility (Fig. 7) which is part of the PAPIRUS (Park of small Installation of R&D for Utilization of sodium) platform. The objective is to validate the thermal hydraulic performances of the current exchange part, as well as to validate in a preliminary way the thermomechanical behavior of the bundle of plates and thus the assembly process. These experimental tests have started in 2013 and will contribute to raise the TRL index from 2 to 4. Complementary to these tests, a series of elementary tests are carried out in parallel on other facilities belonging to the PAPIRUS platform¹.
- Scale 1: tests on a large tests facility named NSET belonging to the CHEOPS platform (see § III.B.2). The NSET facility will allow a power exchange up to 10 MWth. This facility is designed to bring validation on the operation and performance of the heat exchanger module (scale ≈ 1 of the ones foreseen for ASTRID) and components (regrouping a set of modules, scale 1:12) in stationary and transient conditions. These tests will be performed during the ASTRID Basic design phase. The objective is to qualify in detail the heat exchange, the design (especially the design of the sodium manifold), the

manufacturing process with its manufacturing control strategy and the instrumentation for in-service monitoring. These qualification tests will raise the TRL index from 5 to 7.

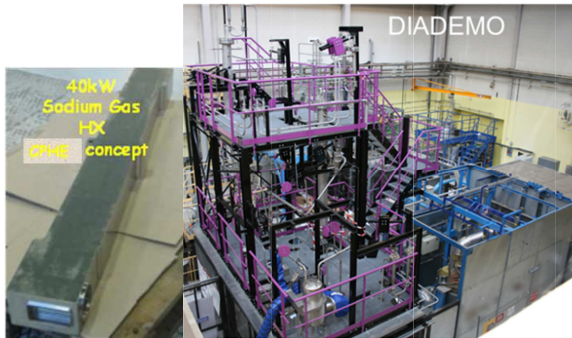


Fig. 7: Picture of the Compact Plate Heat Exchanger (CPHE) and DIADÉMO facility.

III.B. HYDRAULICS and THERMALHYDRAULICS BEHAVIOR OF THE PRIMARY CIRCUIT

An important subject in Sodium Fast Reactors is the hydraulics and Thermal Hydraulics (TH) of the primary vessel.

III.B.1. Needs Identification

The qualification in the field of hydraulics and thermal hydraulics must deal with the following problematics:

- Overall problematics: that is to say thermal hydraulics of the primary circuit as well as natural convection of the primary loop.
- Local problematics which are:
 - Gas entrainment and vortex creation on free surfaces.
 - Gas accumulation within the vessel (in particular in the diagrid).
 - Presence of sodium aerosols in the cover gas plenum and its influence on heat transfer.
 - The non-permanent position of the interface between the gas (and aerosols) and sodium and its impact on the upper part of the inner vessel.
 - Thermal fatigue of the Above Core Structure (ACS) due to core outlet temperature fluctuations.

Some R&D needs concerning the validation of certain thermal hydraulics computing tools must also be taken into account.

Some additional needs in TH are concerning main components such as IHX (Intermediate Heat eXchanger). They will not be presented in this paper.

III.B.2. New experimental needs

Following the analysis of the available experimental database, it has been established that new experiments are needed in order to achieve the qualification of the hydraulics and thermal hydraulics in the primary vessel. Most of them are in water environment but some with sodium are also needed.

Water environment mock-ups:

The GISEH platform consists of several test benches where different R&D studies will be performed. The GISEH platform comprises the facilities operating with simulant fluids (water or air) in support of SFR program. Within it, a new multipurpose facility, today operational (see figure 8), named PLATEAU enables water distribution to mockups.



Fig.8: PLATEAU facility

The following tests are or will be performed on PLATEAU with different mock-ups:

The MICAS mock-up⁶ is the first which has been realized (see figure 9). It represents the ASTRID upper plenum (360°, scale 1/6). The maximum flowrate is 350 m³/h and the range of water temperature is 10 to 60°C. The mock-up is plunged into a water pool to perform Laser velocimetry in order to get a 3D representation of the flow distribution.

MICAS is used to confirm the overall TH behavior of the hot plenum (with possibility to realize transients) and to validate CFD simulation tools. The mains issues to be studied are:

- Free surface deformation because oscillations of the free surface can induce thermal stress on the immersed components.
- Gas entrainment.

- Thermal interface behavior: location, fluctuations.
- TH stability and flow distribution at the IHX inlet.
- Thermal and flow pattern in the ACS.



Fig.9: MICAS mock-up

The MILIPOS0 mock-up, which is currently being designed, will represent the Pump / Diagrid connection (360°, scale 1/6). In this mock-up, will be studied:

- the hydraulic stability of the outlet flow coming from different pump /diagrid connections,
- the hydraulics in the diagrid in normal conditions and asymmetrical situations (break of a pipe, pump shutdown),
- the behavior of the gas (identification of the accumulation zones).

The MISHOCO mock-up will represent a part of the core and the hot plenum. It is currently in the definition design phase and could be a 120° sector and a 1/3 scale.

With an up-to date design and on a bigger scale compared to the MICAS mock-up, it will allow to study thermal hydraulics in the hot plenum, thermal fluctuations at the core outlet and inter wrapper flows. It will also bring new data for the validation of CFD (Computational Fluid Dynamic) simulation tools.

A hot and cold plenum integral mock-up will be useful for the study of the natural convection initiating. The scale is to be defined; it could be about 1/10.

Following the tests that will be performed on MILIPOS0, other tests could be required to demonstrate the elimination of gas entrainment in the core. These tests would involve higher flow rates than those available on PLATEAU.

Sodium environment mocks-up:

In addition to the tests performed in water environment, some needs require a sodium environment.

CHEOPS (see figure 10) is a CEA technological platform which is planned to be built by 2020. It will be a

set of large sodium facilities for component or system qualification. Some experiments are planned in the NAIMMO test section. NAIMMO is a static sodium vessel allowing for static and dynamic conditions. The issue to be studied is the behavior of sodium aerosols (heat transfers, deposition kinetics...) as support to the qualification of the roof slab (penetrations and thermal protections).



Fig.10: CHEOPS drawing - Integration in the environment

The need of a large scale test in sodium environment in order to check the natural convection in the primary circuit and the decay heat removal system efficiency is under evaluation.

Finally, some needs specially require increasing the validation data of the thermohydraulic simulation tools.

This is the aim of the R&D program with JAEA which involves tests to be performed in the PLANDTL sodium facility (in particular for the inter-wrapper flow calculation qualification).

III.C. CORE ASSEMBLIES

III.C.1. Introduction / Background

The ASTRID core assemblies Qualification Plan is dedicated to the licensing of the start-up ASTRID core. This Qualification Plan concerns the internal and external fuel assemblies (RBA), the diversified and independent fast-acting automatic reactor shutdown systems (RBC and RBD), the complementary safety devices dedicated to core damage prevention (RBH), the reflector assemblies and the lateral neutronic protection (RBN) and the mitigation devices.

Two main type of test are performed: out of pile and in-pile test.

The out-of-pile tests consist of mechanical tests, hydraulic and thermal hydraulic tests (in water at sodium/water similarity conditions or in sodium).

The in-pile test consist of Post Irradiation Examinations (PIE) of pin irradiated in the past (PHENIX and SUPERPHENIX programs) and of experimental irradiation tests under representative conditions.

The ASTRID core assemblies Qualification Plan will be completed by the Control Plan and the Performance Rise Plan. The main goal of the first one is to confirm the qualification results in-situ by post-irradiation examination of ASTRID assemblies.

The second one is dedicated to the increasing of assembly lifetime at the equilibrium core conditions. Both will be performed in the ASTRID reactor.

As indicated before, the qualification methodology is based on the use of the Technology Readiness Level method for both main processes necessary to the qualification – the maturity of the manufacturing process and the maturity of the in pile behavior knowledge for material, components and assemblies.

The two paragraphs below present a few examples of out-of-pile and in-pile tests.

III.C.2. Out-of-pile test examples

Usual out-of-pile tests are commonly included to the Qualification Plan and some assembly design studies need dedicated tests to allow maturity level increasing.

For example, mechanical and hydraulic tests are already underway to qualify the concept and components of the fuel assembly and the reactor shutdown systems.

Concerning the fuel assembly, as an example, mechanical tests will be performed in sodium on the innovative head of Upper Neutron Shielding device. These tests consist of the validation of the functional behavior in sodium with the aim to demonstrate the absence of the risk of seizure during handling phases.

Another example concerns the hydraulic tests currently performed in support of the innovative dashpot design of the fast acting shutdown system (RBD). These tests are carried out in water where the thermal-hydraulic properties are close to sodium conditions (sodium/water similarity conditions) in a scale-1 mock-up of the assembly.

The mock-up is representative of the absorber rod bundle, the hexagonal wrapper tube and the dashpot (cylinder and piston), in terms of geometry, mass and materials. Figure 11 hereafter presents the mock-up with the main components.

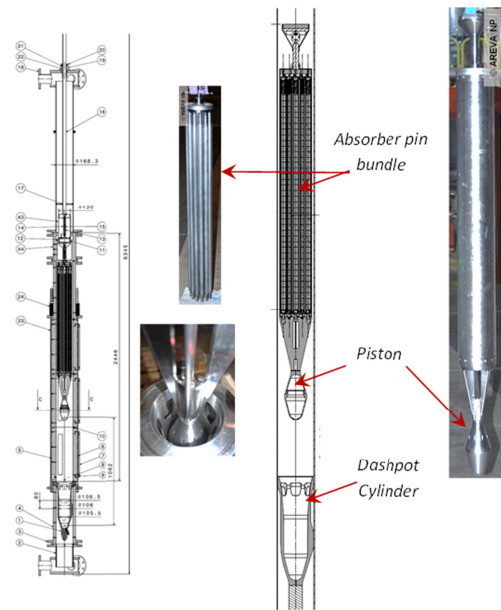


Fig. 11: RBD Dashpot mock-up

These tests began in the beginning of 2016 and the first results confirm the dashpot design (confirmation of no vibration risk at nominal conditions, of rod drop time, of braking kinetic...).

They are conducted by AREVA NP at the Technical Center located at "Le Creusot". Figure 12 shows the test loop with the mock-up.



Fig. 12: Test loop for dashpot hydraulic test – AREVA NP Technical Center

The test campaign will continue with acceleration and chocks measurements and rod drop repeatability tests.

III.C.3. In-Pile Test examples

As indicated before, the maturity, in terms of fabrication and irradiation experience, gained through the French SFR Program allowed developing robust design and material solutions for the first ASTRID cores.

These solutions have to be validated, either by post irradiation examinations on irradiated pins or structure from PHENIX and SUPERPHENIX reactors, or by irradiation experiments under representative conditions.

In the outline of Qualification Plan, several experimental irradiation tests are being designed, firstly within the framework of CEA-JAEA Implementing Arrangement on the ASTRID Program and SFR Collaboration (irradiation test planed in JOYO reactor) and also in Russian Fast Reactors (BN600 for fuel tests and BOR-60 for steel materials and absorber).

As an example, the MACARON irradiation test dedicated to absorber pin design studies is currently designed and discussed with BOR-60 teams of RIAR (Russian Research Institute of Atomic Reactors).

Concerning the PIE on irradiated pins or structure from PHENIX and SUPERPHENIX reactors, a dedicated CEA program named "PHENIX Treasure"⁷ is planned with the aim to contribute to the qualification of the materials and the concept of the ASTRID assemblies.

In this framework, we can mention the PIE programs on MATINA 2/3 pins dedicated to the Reflector development with magnesium oxide pins or the PIE program on PHENIX standard fuel dedicated to CEA fuel modelling code improvement (CEA fuel simulation tool called GERMINAL).

We can also mention PIE program on ZEBRE pins then on PAVIX 8 irradiated fuel pins⁸ which the main goal is the validation of the axially heterogeneous fuel behavior. ZEBRE and PAVIX 8 fuel pins were indeed constituted, like ASTRID pins, by fertile and fissile columns distributed axially along the pin.

The Burn-Up reached at the end of PAVIX 8 irradiation was about 12 to 13 at% close to the ASTRID internal core fuel pin average Burn-Up.

The PIE program on ZEBRE fuel pins was already performed in CEA hot laboratory (see figure 13) and the PAVIX 8 PIE program is underway and will be completed at the end of 2017.

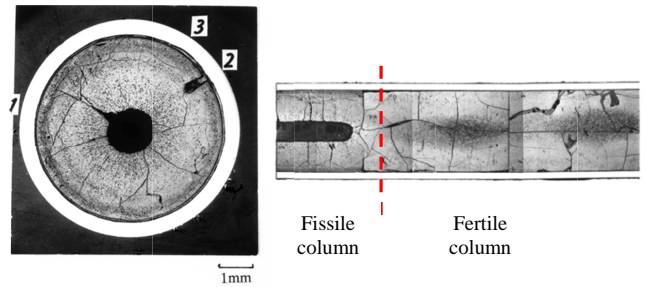


Fig. 13: Metallography – ZEBRE Fuel Pellets – fissile/fertile interface (12.1 at %)

All the fuel PIE results obtained on PHENIX and SUPER PHENIX pins will allow reaching TRL 5/6 level and the experimental irradiation tests planned under representative conditions in JOYO or BN 600 reactors will complete the fuel pin qualification by confirmation of the in-pile fuel behavior step and will allow achieving TRL6 level. The TR7 and 8 levels will be reached during ASTRID operation through the carrying out of the Performance Rise Plan.

IV. CONCLUSIONS

The qualification which has to be performed is an important task especially when the industrial project is integrating several significant innovative options.

In addition, in ASTRID case, due to its wide number of engineering participants, it was necessary to implement standardized qualification processes concerning equipment and systems as well as simulation tools.

The qualification approach must be attentive to the evolutions of choice options of the project throughout its progress.

The prioritization among the different needs is absolutely necessary, because every project has cost and time constraints.

Thus, the evaluation of a reasonable but acceptable level of performance in regards with the planned R&D program will lead to prioritize the actions and to identify several major project risks.

ACKNOWLEDGMENTS

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ACRONYMS

| | |
|---------|--|
| ASTRID: | Advanced Sodium Technological Reactor for Industrial Demonstration |
| AVP2: | Conceptual design studies, phase 2 |
| CEA: | French Atomic Energy Commission |
| CFD: | Computational Fluid Dynamic |
| CPHE: | Compact Plate Heat Exchanger |
| DB-HIP: | Diffusion Bonding by Hot Isostatic Pressing |
| HX: | Heat eXchanger |
| IHX: | Intermediate Heat eXchanger |
| IRL: | Integration Readiness Level |
| JAEA: | Japan Atomic Energy Agency |
| MRL: | Manufacturing Readiness Level |
| PCS: | Power Conversion System |
| PIE: | Post Irradiation Examinations |
| R&D: | Research and Development |
| RBA: | Internal and external fuel assemblies |
| RBC: | Independent fast-acting automatic reactor shutdown systems |
| RBD: | Diversified fast-acting automatic reactor shutdown systems |
| RBH: | Complementary safety devices |
| RBN: | Reflector assemblies and the lateral neutronic protection |
| RIAR: | Research Institute of Atomic Reactors |
| SFR: | Sodium Fast Reactor |
| SGHE: | Sodium Gas Heat Exchanger |
| SRL: | System Readiness Level |
| ST: | Simulation Tool |
| TH: | Thermal Hydraulics |
| TRL: | Technological Readiness Level |
| VVUQ: | Verification, Validation and Uncertainties Quantification |

4. G. LAFFONT et al. "ASTRID power conversion system based on steam and gas options", *Proc. of ICAPP 2014, Paper 14116, p. 447-455*, ANS, Charlotte, USA (2014).
5. L. CACHON et al. "Status of the Sodium Gas Heat Exchanger (SGHE) Development for the Nitrogen Power Conversion System Planned for the ASTRID SFR Prototype", *Proc. of ICAPP 2015, Paper 15439*, SFEN, Nice, France (2015).
6. D.GUENADOU, I. TKATSHENKO and P. AUBERT" PLATEAU facility in support to ASTRID and the SFR program: an overview of the first mock-up of the ASTRID upper plenum, *MICAS 16th International Topical Meeting on Nuclear Thermal-Hydraulics (NURETH-16)*, Chicago, USA, Paper 12895 (2015).
7. I. MUNOZ et al. "Recovery of Nuclear materials from PHENIX to support qualification of ASTRID design options" *Proc. Of FR13 Conference, Paris, France (2013)*.
8. B. RABU et al. "Post-Irradiation Examinations on PHENIX axially heterogeneous pins relevant to ASTRID fuel design: ZEBRE and PAVIX irradiations" *Proc. of ACTINIDES 2013 Conference, Karlsruhe, Germany (2013)*.

REFERENCES

1. G. RODRIGUEZ and al., "Qualification program of the ASTRID SFR project: Definition, Methodology and associated Risk Evaluation & Management", *Proc. of ICAPP 2015, Paper 15093*, Nice, FRANCE (2015).
2. J. A. FERNANDEZ, SANDIA Report, "Contextual Role of TRLs and MRLs in Technology Management", SAND2010-7595 (2010).
3. G. GAILLARD-GROLEAS and al., "Improvements in simulation tools to be developed within the framework of the ASTRID project", *Proc. of ICAPP 2016, Paper 16385*, San Francisco, CA, USA, (2016).