Framework for Irradiation Experiments II (FIDES-II)

Strategic Plan

A product of the FIDES-II Membership, April 2023

TABLE OF CONTENTS

Executive Summary

FIDES-II was established following the shut-down of the Halden Reactor to address the ongoing irradiation testing needs of stakeholders across the nuclear power sector. Irradiations and accompanying post irradiation examination (PIE) within FIDES-II are conducted at multiple facilities in several countries, where the main aim is to collect data to support qualification, licensing, and safety analyses of nuclear fuel, cladding, core components, and structural materials for their safe and efficient use in current and future nuclear power plants (NPPs). This document describes the strategic objectives of FIDES-II until ca. 2030, in terms of Research Objectives and Framework Objectives.

The primary purpose of FIDES-II is to acquire data through irradiation testing. Research Objectives are described in terms of the data needs to be addressed via irradiation testing which span simple to complex irradiation tests of mature and less-mature fuel, cladding, core components, and structural material concepts, for application in both current and future NPPs.

Framework Objectives are related to building and maintaining a sustainable, robust framework, that in-turn enables conducting the necessary irradiation testing. Framework Objectives include the FIDES-II position on supporting and developing facilities and capabilities. While it is not the primary mission of FIDES-II to maintain or develop facilities and capabilities separate from a defined research program, it is recognized that such facilities and capabilities are essential for addressing both existing and future Research Objectives. Other key Framework Objectives are that the FIDES-II experimental program should aim to grow to ca. 5 to 10 JEEPs in parallel by ca. 2030. For the experimental program composition to be considered appropriately balanced, equal attention should be paid to fuel/cladding- and structural materials experiments, while it is recognized that a greater percentage of the budget will likely be allocated to fuels activities, due to the increased complexity of those tests.

Acronyms and Abbreviations:

AOO	Anticipated Operating Occurrence
AR	Advanced Reactors
ASME	American Society of Mechanical Engineers
BDBA	Beyond Design Basis Accident
BWR	Boiling Water Reactor
CCA	Cross Cutting Activity
DBA	Design Basis Accident
DNB	Departure from Nucleate Boiling
DPA	Dislocations Per Atom
FFRD	Fuel Fragmentation, Relocation, and Dispersal
FIDES	Framework for Irradiation Experiments
Gen III	Generation three (nuclear plant)
Gen IV	Generation four (nuclear plant)
GFR	Gas Fast Reactor
HAZ	Heat Affected Zone
HEA	High Entropy Alloy
HRP	Halden Reactor Project
HTGR	High Temperature Gas Reactor
IASCC	Irradiation Assisted Stress Corrosion Cracking
IFA	Instrumented Fuel Assembly
JEEP	Joint Experimental Program
LOCA	Loss of Coolant Accident
LWR	Light Water Reactor
MOX	Mixed Oxide
MTR	Materials Test Reactor
NEA	Nuclear Energy Agency
NEST	Nuclear Education, Skills and Technology Framework
NPP	Nuclear Power Plant
OA	Operating Agent
ODS	Oxide Dispersion Strengthened (alloy)
OECD	Organization for Economic Cooperation and Development
PCI	Pellet Clad Interaction
PCMI	Pellet Clad Mechanical Interaction
PIE	Post Irradiation Examination
PIRT	Phenomena Identification and Ranking Table
PWR	Pressurized Water Reactor
RIA	Reactivity Insertion Accident
RIS	Radiation Induced Segregation
SCC	Stress Corrosion Cracking
SCWR	Super Critical Water Reactor
SMR	Small Modular Reactor
TRL	Technical Readiness Level
VVER	Water-Water Energetic Reactor (Voda-Vodyanoi Energetichesky Reaktor)

1 Introduction

1.1 Background

There is an ongoing need among the global community of nuclear power sector stakeholders[1] to conduct irradiation testing in material test reactors (MTRs) to support the safe and efficient operation of nuclear fuel, cladding, core components, and structural materials in current and future nuclear power plants (NPPs)[2], where the ultimate objective of such irradiation testing is to ensure and improve safety and efficiency of the installations.

In recent decades, the OECD-NEA Halden Reactor Project (HRP) was the primary framework for stakeholders to conduct joint international fuel and materials irradiation testing. The unexpected closure of the Halden Reactor in 2018 resulted in sudden loss of capacity and capabilities for performing such irradiation experiments and revealed the vulnerability with consolidating in-pile nuclear fuel and materials testing, almost exclusively, at a single facility.

FIDES-II was created to effectively address the consequences of the shut-down of the Halden reactor, offering a new OECD-NEA framework for conducting joint international fuel and materials irradiation experiments. These are performed utilizing a robust network of multiple MTRs, instead of a single irradiation facility, as was the case in HRP. Besides this, the framework and membership base of HRP and FIDES-II are very similar.

1.2 Purpose of FIDES-II

FIDES-II aims to be the premier international framework for performing joint, international, nuclear fuel and materials irradiation experiments to acquire data in support of operation, safety, qualification, and licensing of nuclear fuels, claddings, and structural materials in current and future NPPs. This is formally expressed in the following excerpt from the FIDES-II agreement [1], where the purpose is to:

1) *Establish a framework for international collaboration to provide continuity and sustainability of experimental capacities, foster and facilitate irradiation experiments to test materials and fuels, through the gathering of a large multinational community in the field of safety, industry and research that will share goals, resources and results to define and implement joint experimental programmes (JEEPs) and cross-cutting activities (CCAs).*

2) *Create and provide the necessary conditions, including the due identification of needs, funding, and capacities by providing access to JEEP Facilities for the use and sustainability of the current and future world-wide available nuclear capacities (research reactors, hot cells, related skills, etc.) to allow for the implementation of JEEPs and any other activity associated with their implementation.*

Within FIDES-II, the focus is on data collection via irradiation testing and accompanying post irradiation examination (PIE). PIE or out-of-pile experiments without associated irradiation testing should be avoided within FIDES-II, since there are separate international frameworks for these efforts.

---

[1] Nuclear Power Plant operators, regulators, national laboratories, Technical Support Organizations, etc.

[2] In this document, future NPPs are also referred to as *next generation NPPs*, *Advanced Reactors*, and *Generation IV Reactors (Gen IV)*, and also include Light Water (LW) Small Modular Reactors (SMRs).

1.3 Scope of this document

This document gives an overview of the strategic objectives of FIDES-II, comprising a summary of the data needs for nuclear fuel, cladding, and structural materials to be addressed by means of irradiation testing, as well as other objectives pertaining to building and maintaining a robust framework that in-turn enables the irradiation testing. The prioritization of current and future irradiation tests and other goals is outside the scope of this document and is not addressed here; however, important near-term data needs are identified in this document and it will be left to specific JEEPs to prioritize and address these needs.

The time-consuming nature of conducting irradiation experiments and associated PIE means that the research goals cover a period of years. Some data needs can be met by performing irradiation experiments in the immediate future, while other data needs will be met incrementally over time, likely over a span of many years, or even decades. This document pertains to the period extending to ca. 2030.

2 Strategic Objectives

The strategic objectives of FIDES-II are divided into two categories: *Research Objectives*, and *Framework Objectives*. Research Objectives correspond to the data needs to be primarily addressed via irradiation testing, and Framework Objectives correspond to the needs for maintaining a sustainable, robust framework, with available expertise, capacity, and capabilities, etc. to enable the achievement of the Research Objectives.

2.1 Research Objectives

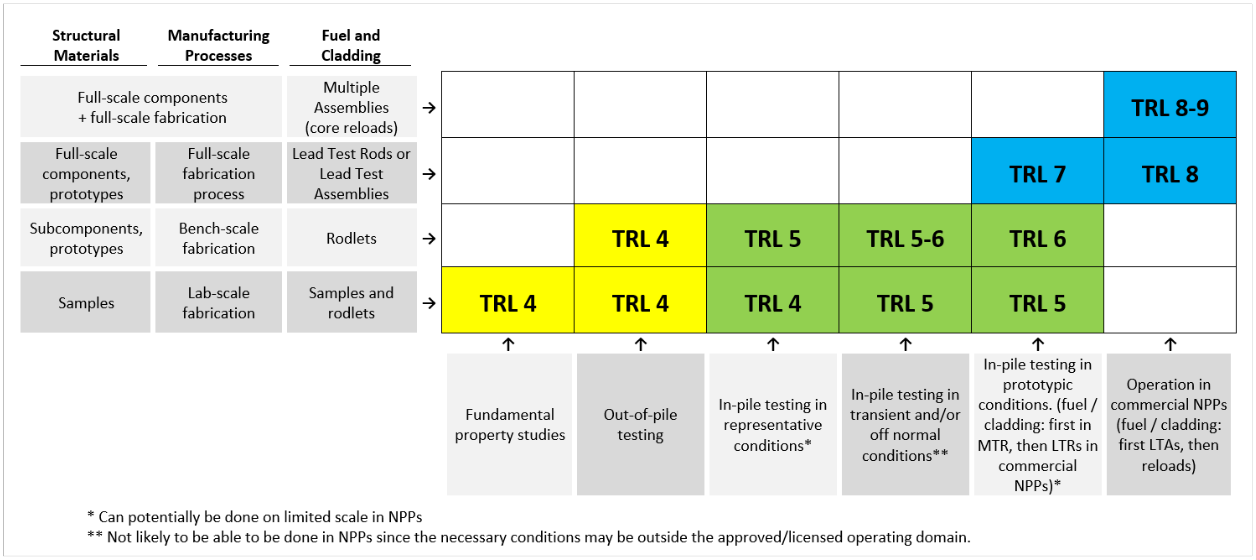
The primary purpose of the FIDES-II framework is to facilitate acquisition of data that can only be obtained through irradiation testing and accompanying PIE, ultimately in support of operation, safety, qualification, and licensing of nuclear fuels, claddings, and structural materials in current and future NPPs. The data needs comprise determining fundamental properties under irradiation, evaluating safety and performance of the selected fuels, claddings, core components, and structural materials in relevant in-pile environments and operation scenarios, as well as acquiring information of relevance to develop models and fuel performance codes.

Despite being focused on acquisition of data via irradiation testing, some out-of-pile testing may be warranted/necessary within FIDES-II, when it is complementary to the in-pile/PIE data or otherwise needed to interpret the in-pile/PIE data. Since many nuclear fuels, claddings, and structural materials are relevant for use in both current and future NPPs, and since the stakeholders for current and future NPPs are largely the same, FIDES-II activities may be relevant for both current and next generation NPPs.

The approach to achieving the Research Objectives is described in section 2.1.1, while the Research Objectives, in terms of data needs, are summarized in the specific context of FIDES-II in section 2.1.2 for nuclear fuel and cladding, and section 2.1.3 for structural materials and manufacturing processes.

2.1.1 Technical Readiness Level

The aim of collecting data from irradiation testing and PIE is to assess and predict the safety and performance of currently-used as well as future fuel, cladding, core components, and structural materials by developing a robust understanding of the results of these irradiation experiments, including through modelling. When dealing with innovative fuels, claddings, core components, and structural materials and associated manufacturing processes, it is useful to apply the concepts of the Technical Readiness Level (TRL). Figure 1 was developed by the authors of this document (members of FIDES-II) and illustrates the progression of TRLs, for innovative fuel and cladding, structural materials, and manufacturing processes, going from TRL 4, studies of fundamental properties, to TRL 8-9, full-scale use in NPPs, indicating the relationship between TRL, the types of test objects, and the method/conditions of testing.



Structural Materials	Manufacturing Processes	Fuel and Cladding							
Full-scale components + full-scale fabrication		Multiple Assemblies (core reloads)	→						TRL 8-9
Full-scale components, prototypes	Full-scale fabrication process	Lead Test Rods or Lead Test Assemblies	→					TRL 7	TRL 8
Subcomponents, prototypes	Bench-scale fabrication	Rodlets	→		TRL 4	TRL 5	TRL 5-6	TRL 6	
Samples	Lab-scale fabrication	Samples and rodlets	→	TRL 4	TRL 4	TRL 4	TRL 5	TRL 5	
				↑	↑	↑	↑	↑	↑
				Fundamental property studies	Out-of-pile testing	In-pile testing in representative conditions*	In-pile testing in transient and/or off normal conditions**	In-pile testing in prototypic conditions. (fuel / cladding: first in MTR, then LTRs in commercial NPPs)*	Operation in commercial NPPs (fuel / cladding: first LTAs, then reloads)

* Can potentially be done on limited scale in NPPs
** Not likely to be able to be done in NPPs since the necessary conditions may be outside the approved/licensed operating domain.

Figure 1, Illustration of the general progression of Technical Readiness Level for innovative fuel and cladding, structural materials, and manufacturing processes, starting with investigations of fundamental properties, and ending with use of full-scale fuel assemblies and components in NPPs.

As illustrated in Figure 1, the yellow cells roughly correspond to cases where out-of-pile testing is the primary test method, the green cells correspond to cases where irradiation testing is primarily conducted in MTRs, and the blue cells primarily correspond to irradiation in NPPs. Note, however, that these domains are not exclusive: in-pile testing may, in some cases, be conducted in the yellow domain, some irradiations that typically fall within the blue domain (in NPPs) may be conducted in the green domain (in MTRs), and some irradiations that have traditionally been performed in MTRs may be conducted in NPPs.

Importantly, the TRL applies to a specific fuel, cladding, structural material, and/or manufacturing process in a specific environment or specific set of operating conditions, so the effective TRL will necessarily be considered reduced for an otherwise high-TRL fuel, cladding, structural material, or manufacturing process, when it is introduced into a “new” environment. Thus, currently used (i.e., TRL 8-9) fuel rod designs and/or structural materials/components may require further irradiation testing, corresponding to a lower-TRL, if they are to be qualified for use in new/extended environments or operating conditions, or if other previously irrelevant, or not-yet-fully-understood behaviour is observed and/or becomes relevant.

A single irradiation test may address data needs across multiple TRLs, e.g., where a structural material sample may “piggy-back” on a fuel rodlet test if there is available space, or where the fundamental properties of the material sample may be investigated (i.e., TRL 4) during the same irradiation where the fuel rodlet is tested in prototypic conditions (i.e., TRL 6).

As stated, PIE or out-of-pile experiments without an associated irradiation test should be avoided within FIDES-II. However, some out-of-pile testing may be warranted/necessary within FIDES-II when complementary to, or needed to interpret, the in-pile/PIE data.

2.1.2 Nuclear Fuel and Cladding

The data needs are described in this document for three categories of fuel and cladding: *Current Fuel, Near-term New Fuels, and Advanced Fuels*. The fuel and cladding materials that fall within these categories are shown in Table 1 and can generally be considered to have high-, medium-, and lower-level TRLs, respectively. Note that the definitions of the fuel types in the table generally correspond to the fuel and cladding descriptions in [2], where current fuel corresponds to fuel rod designs in use in current NPPs, Near-term New Fuels correspond to fuels and claddings targeted for relatively near-term use in current NPPs[3], and where Advanced Fuels correspond to fuels and claddings intended for use in future NPPs, but that can also potentially be used in current NPPs. However, some materials that are being considered for cladding in GenIV concepts are not listed in Table 1, although they are included in the list of structural materials (see section 2.1.3).

Table 1, Categorization of fuel and cladding.

	Fuel and Cladding Material Type	**Current Fuel**	**Near-term New Fuels**	**Advanced Fuels**
Cladding Materials	“Standard” Zirconium-based cladding alloys (including liner claddings)	x		
	Coated and improved Zr-alloys. *The primary candidate for PWRs is Cr-based coatings. Coating materials for BWRs are still under development.*		x	
	Refractory metal claddings: Lined Mo-alloy cladding		x	
	Advanced steel cladding: FeCrAl			x
	SiC			x
Fuel Types	“Conventional” UO_2 and (U,Pu)O2	x		
	“Conventional” UO_2, > 5% enrichment	x		
	Doped UO_2 (e.g. with Gd, Cr)	x[†]	x[†]	
	Improved UO_2: High-thermal conductivity UO_2 fuel		x	
	High-density fuel (Nitride, Silicide, Carbide, and Metallic fuels)			x
	TRISO-SiC-composite pellets			x

[†] Doped UO_2 fuel is an example of a fuel at two different TRLs based on the stakeholders’ perspectives, where doped fuel may be considered as a Current Fuel and a Near-Term New Fuel. Doped pellets have been a reload product in Boiling Water Reactors (BWRs) for about a decade and constitute full cores in some BWR plants (corresponding to TRL 9), but doped fuels are uncommon in Pressurized Water Reactors. As such, data needs for doped fuels going forward can be considered as belonging to both the Current Fuel and Near-term New Fuel categories.

---

[3] Note that this includes what is typically referred to as “Accident Tolerant Fuel” and “ATF”; however, such terms were avoided in this document since there are no clear, internationally-agreed-upon definitions of these terms.

Appendix A contains tables for Current Fuel, Near-term New Fuels, and Advanced Fuels, where the types of data needed for each category are briefly described and the typical type of irradiation experiment performed to acquire that type of data is indicated. In general, the needs for assessing performance of, developing, and/or qualifying/licensing nuclear fuels and claddings consist of establishing and understanding the following [3]-[10]:

- Fundamental properties under irradiation
- Fuel and cladding performance under steady-state conditions
- Response to power events
- Response to Loss of Coolant Accidents
- Response to Reactivity Insertion Accidents
- Response of failed fuel rods to transients

These needs are valid for new materials (e.g., SiC$_f$-/SiC cladding tubes) as well as existing materials under new conditions (e.g., Zr based cladding with UO_2 beyond the current burnup range or subjected to the transients anticipated in LWR SMRs).

2.1.3 Structural Materials and Manufacturing Processes

Data needs are described in this document for the following categories of structural materials: *Current Materials* (currently used in LWRs), *Near-term New Materials* (e.g. for use in current NPPs or near-term SMR applications, as well as in Advanced Non-LWR (ANLWR) prototypes), and *Advanced Materials* (for use in future NPPs, including ANLWRs). Structural materials, grouped in the categories *Nickel Alloys, Low Alloy Steels, Austenitic Stainless Steels*, and *Other Materials,* are listed in Table 2 under the relevant application. Nickel alloys, low alloy steels and austenitic stainless steels include the materials used in current NPPs and those presently identified for potential use in advanced reactors (i.e., near-term SMRs and future generation NPPs). Other materials include, for example, additively manufactured (AM) materials, graphite, carbon and SiC composites, FeCrAl alloys and oxide-dispersion steels, mainly for advanced reactors, where more extreme conditions (e.g., temperature, coolant chemistry) are expected. However, advanced materials are not necessarily precluded from current reactor designs. In addition to the base materials listed in Table 2, the associated joints and weld materials must be qualified for the same conditions as the base materials; however, these materials are not listed here. Aluminum alloys are also not included since they are only suitable for low temperature (<100°C) operating reactors, i.e., MTRs, which are currently considered outside the scope of FIDES-II.

Table 2, Categorization of structural materials.

Material Category[‡]	Current Materials (i.e. in use in LWRs)	Near-term Materials (e.g. SMR applications and next generation reactor prototypes)	Advanced Materials
Nickel Alloys	Super alloys, Hastelloy N and variants, Alloys 690 and 718	Super alloys, Hastelloy N and variants, Alloys 690 and 718, and Additive Manufacturing (AM) grades of these alloys, 800H, 617	
Low Alloy Steels	Reactor Pressure Vessel (RPV) steels, e.g. SA-533 Grade B Class 1, SA-508 Class 2, 16MND5, and CrMo steels		

Austenitic Stainless steels	3XX series (e.g. 316L&H, 304L&H, 347, and 321), cast austenitic	3XX series (e.g. 316L&H, 304L&H), AM316, cast austenitic	Alloys 709, D9, 15-15Ti
Other Materials		Ferritic/Martensitic (F/M) high Cr steels; alumina forming steels (FeCrAl as F/M; alumina forming austenitics, AFA; any AM material, either of a type already in use or not.	Ferritic/Martensitic (F/M) high Cr steels and their ODS (oxide dispersion strengthened) versions; alumina forming steels (FeCrAl as F/M; alumina forming austenitics, AFA), refractory materials such as Mo and V based alloys, ceramics for high temperature applications (e.g., carbon and SiC composites, graphite, and Zr_3Si_2), high entropy alloys (HEA). All of these may be AM materials.

‡ Weld materials and joints associated with each category of structural base material must be qualified for the same conditions as the base materials. Note that these materials are not specified in this table.

‡‡ Not necessarily already used for LWRs, but considered for future ones

Appendix B contains a more detailed summary of testing needs for structural materials. These are generally focused on the following issues:

- Irradiation hardening and embrittlement [12]
- Irradiation assisted stress corrosion cracking (in water) [13]
- Synergy between irradiation and corrosion/dissolution/erosion in non-aqueous environments [14], [15], [16], [17], [18]
- Radiation-induced swelling [19]
- Radiation-induced creep and stress relaxation [20]
- Synergy between irradiation and fatigue/creep-fatigue [21]
- Combined effect of mild irradiation and thermal ageing [22]
- Microstructural and microchemical evolution under irradiation (e.g., defect production, solute clusters and precipitates, radiation induced segregation, etc.) [23], [24], [25], [26]

All these issues need to be addressed for baseline materials, welds/joints, and also heat-affected zones (HAZ), i.e., regions of the material that have been affected by heat during welding/joining (the details, of course, depend on the welding/joining technique). It is important to consider the evaluation of microstructural and microchemical evolution under irradiation during the design of a test series. If this is not able to be explicitly included or completed as part of the irradiation testing, experiment designers should ensure that components/materials from the irradiated experiment are available for such evaluation in follow-on efforts.

It can be noted that, depending on the phenomenon to be studied, the temperature regime of interest may differ significantly. E.g., hardening and ensuing embrittlement in a steel will occur below 400°C, the lower temperature, the harsher; while radiation-induced swelling and creep will occur above 330°C. Thus, the temperature range of the experiment needs to be accurately selected and appropriately controlled. In addition, the flux of MTRs may not always be representative of operation conditions, thus requiring reliable correlations to correctly interpret the results. For example, for RPV steels the MTR flux may be 4-5 orders of magnitude higher, requiring that this difference be addressed in safety assessments based on such data.

2.2 Framework objectives

The FIDES-II Framework Objectives are those goals that are not specific to the Research Objectives, and which reflect the needs for maintaining a sustainable, robust framework, with available expertise, capacity, and capabilities to enable achieving the Research Objectives. Framework Objectives are grouped into the following categories and are further described in the sections 2.2.1 through 2.2.5:

- **Maintaining and Developing Capabilities:** Ensuring relevant irradiation and PIE facilities and experimental capabilities are maintained and developed, such that they are available to the FIDES-II framework when needed.
- **Size and Composition of Experimental Program:** The number and mix of experiment types to be performed should ensure that members obtain sufficient value in return for their membership contributions to the framework and should be sufficient to attract and maintain a robust membership community.
- **Maintaining and Expanding the Size and Composition of FIDES-II Framework:** The number and type of framework members should be maintained at a sufficient level to provide the necessary budget, facilities, and expertise to maintain a sufficient size and composition of the experimental program.
- **Community Building:** Building and fostering a robust community promotes collaboration, and thus enhances the value of experiments, which in-turn encourages continued participation and aids in attracting new members.
- **Cross-cutting Activities:** Extending the value of JEEPs and acquired data beyond the value of just the data itself, e.g., modelling tools' assessment, training and education, data preservation, etc.

2.2.1 Maintaining and Developing Capabilities

While it is not the mission of FIDES-II to maintain or develop facilities and capabilities, the existence and availability of the needed facilities and capabilities is a pre-requisite for being able to accomplish the FIDES-II Research Objectives. Independently of FIDES-II, it is also a general concern for nuclear power stakeholders that the necessary facilities and capabilities be available when needed [11]. Therefore, from the perspective of the FIDES-II members, it is desirable that appropriate support is given to ensure that relevant facilities and capabilities are maintained and developed to ensure their availability going forward.

The focus of the research conducted within FIDES-II is on irradiation testing, but it is important to note that while much data is acquired "online" during the irradiation tests, significant data typically comes from PIE, performed at research reactor sites and in dedicated hot laboratories. It can additionally be noted that samples are prepared for irradiation in hot laboratories. PIE and sample preparation are important components of acquiring data from irradiation testing, and PIE facilities / hot laboratories are therefore equally of concern regarding the FIDES-II position on maintaining and developing capabilities.

The needs for maintaining and developing facilities and capabilities can be broken down into the following priorities:

1) <u>Maintain current facilities and capabilities</u> i.e., prevent further loss of facilities and capabilities.
2) <u>Increase capacity and develop capabilities in existing facilities</u>, both to replace what was lost with the shutdown of the Halden Reactor and to enable needed testing in conditions beyond what was possible/feasible in Halden.
3) <u>Add redundancy and build in commonality,</u> when possible, to build a more robust network of available facilities/capabilities, to mitigate unexpected unavailability of specific facilities/capabilities and to account for any experimental bias connected to specific facilities/capabilities.

In the context of FIDES-II, the facilities and capabilities are primarily the responsibility of the Operating Agents (OAs). It is recognized that each of these individual OAs is governed by their own set of local/national boundary conditions which impose varying constraints on them, thus determining the final strategy concerning the maintenance and development of facilities and capabilities. This further implies that the support necessary to ensure maintaining and developing facilities and capabilities may vary depending on the OA, e.g., OAs may have varying degrees of other sources of support for this purpose.

Short of providing direct funding to OAs solely to operate, maintain, or develop facilities and capabilities, FIDES-II is able to provide support in several ways:

- Perform experiments within FIDES-II JEEPs using the needed facilities and capabilities. This explicitly demonstrates the ongoing needs, contributes funding towards the use of such facilities and capabilities, and aids in maintaining expertise in their use.
- Communicate clearly with OAs in good time about future proposed experiments which make use of either existing or not-yet-developed facilities/capabilities, with the aim to provide OAs' with longer-term view of the potential need for existing and future facilities/capabilities. This

will provide input towards: justification for maintaining existing facilities and capabilities; direction for development of new capacities and capabilities; and a background for finding synergies with other complementary efforts that may, for example, co-fund development of needed capabilities.

- Allow for the possibility of including funding within JEEPs to support development of new capabilities, when required for the associated irradiation testing.
- Promote and facilitate cooperation between stakeholders when new capabilities are being developed so that “transferable” solutions can be created whenever possible, such that they may be readily adaptable for use in multiple facilities/organizations.

It is, however, outside the scope of this document to specify in detail which capabilities and capacities should be maintained and/or developed and which areas should be targeted for finding transferable solutions, or where equipment, instruments, techniques, etc. could be developed to be readily adaptable for use in multiple facilities.

2.2.2 Size and Composition of Experimental Program

The number and types of experiments conducted within FIDES-II should quantitatively and qualitatively be of sufficient value to the members, such that the members continue to find value in their continued membership in FIDES-II.

In the inaugural year of FIDES-II (2022), there were three ongoing JEEPs. It is desired that the size of the experimental program is gradually grown to include 5 to 10 JEEPs in parallel by ca. 2030. This number of experiments is generally regarded among the FIDES-II members as sufficient to ensure that each member will obtain data which they consider valuable and reflects a program that is sufficiently large to justify their continued participation in the framework, i.e. a program of this size ensures that it is more likely that the particular interests of each member are met at least in one of the JEEP.

For the experimental program composition to be considered appropriately balanced, equal attention should be paid to fuel/cladding and structural materials experiments irrespective of the fact that most likely a greater percentage of the budget will end up being allocated to fuel/cladding activities due to the increased complexity of those tests. This will aid in creating and maintaining a robust program with participation from experts in these overlapping fields and will create synergy from the perspective of the funding organizations that will further help in justify continued membership.

The complexity-level of experiments conducted within FIDES-II should not be limited to the highest complexity level (most time-consuming and most expensive integral tests), nor should it be limited to relatively simple experiments (less time-consuming, and less expensive separate effects tests). Rather, the aim is for the experimental program to be balanced, with integral tests complemented by separate effects tests in representative conditions and/or so-called piggy-back experiments. In these, materials of interest occupy otherwise free space in an irradiation rig, or space otherwise filled with dummy materials for, e.g., modelling purposes (model alloys), or with low TRL materials, where the behaviour under irradiation is almost totally unknown, so that any data under any conditions may be valuable.

This corresponds to the progression of TRL via irradiation testing of fuel, cladding and structural materials, as described in section 2.1.1, where “simple” irradiations are first performed to determine basic properties, after which the tests become progressively more complex, thus increasing the TRL (illustrated in Figure 1).

In addition to balancing the complexity-level of experiments, a balance should also be kept between experiments using existing equipment and techniques vs. experiments using still to be developed equipment and techniques. This directly affects the expected time or JEEP duration until results or data can be expected as well as the likelihood of unexpected delays and cost increases of an experiment or JEEP. Such a well-balanced approach would allow developing new capabilities, while also ensuring that the needs of framework participants more interested in data generation are equally met.

In summary, the aims for the size and composition of the experimental program are the following:

- Grow to ca. 5 to 10 JEEPs by ca. 2030.
- Aim for ca. 50% fuel/cladding experiments and ca. 50% structural materials experiments.
- Experimental program to be comprised of complex as well as relatively simpler experiments.
- Experimental program to be comprised of experiments using existing equipment and techniques as well as experiments using still to be developed equipment and techniques.

2.2.3 Size and Composition of FIDES-II Framework

The number and type of members in FIDES-II affects the robustness and ultimately the sustainability of the framework. It is desirable to have many members since this enables the cost and risk of experiments to be shared at an acceptable level, effectively facilitating performance of experiments that are often too costly for a single member to fund on their own.

It is also desirable that the membership of FIDES-II is made up of a wide variety of nuclear power stakeholders, including fuel and reactor vendors, regulators, Technical Support Organizations, universities, national laboratories, etc. According to their different roles in the nuclear power sector, participants from these types of members bring their competing and complementary perspectives to the experiments. Experience from the HRP demonstrated that when these various stakeholders collaborate on experiments, including specification and interpretation, the acquired data is of the highest value, and facilitates acceptance of the results by the stakeholders.

While there is no specific target for the number of members or for the number of each type of stakeholder, there are nevertheless several advantages to recruiting additional members:

- Increase in the total budget (or reduced cost burden on members if the budget is kept constant).
- Participation from new experts, giving added insight into experiment design, analysis, etc., ultimately increasing the value of the experiments.
- Possible participation from new OAs, potentially making additional capacity, facilities, and capabilities available to FIDES-II.

In summary, the following points should be considered regarding the FIDES-II framework membership community:

- It is advantageous to add new members with regard to budget, expertise, facilities, and reach of the FIDES-II framework

- The types of stakeholders comprised by the membership should be considered when recruiting new members, so that stakeholders with valuable and perhaps unrepresented, or under-represented expertise, facilities, perspectives, may be targeted for recruitment.

2.2.4 Community Building

Fostering a robust community within the FIDES-II membership is an important aspect of ensuring that the framework is a long-lasting and effective one for conducting joint international irradiation experiments. A robust community facilitates open, honest discussions among members, and adds value to experiments when all stakeholders (regulators, vendors, NPP operators, research centers, etc.) can openly discuss and agree on experiment specifications and interpretation of results. This in-turn adds value to the framework, encouraging continued participation by the members, and giving prospective new members confidence in the FIDES-II framework.

It should be noted that the robust community within HRP is regarded as one of the key success factors of that long-running (over 60 years) framework. In the case of HRP, the community was actively cultivated to ensure it remained robust. It is likewise warranted within FIDES-II to actively cultivate the community, especially considering that FIDES-II is newly established.

Based on the HRP example, Framework Community Building efforts include activities such as:

- Hosting TAG and GB meetings at the members' sites, including site tours when possible.
- Holding "conference"-type meetings open to participants from member organizations who are outside the normal TAG, GB, and JEEP Core Groups, and where members are encouraged to present non-FIDES-II related work facilitated by FIDES-II JEEPs, etc. (similar to the Enlarged Halden Programme Group meetings hosted every 1.5 years). Such meetings with HRP included (engineer-friendly) social events and banquets.
- Establishing cooperation frameworks with external scientific communities dedicated to nuclear materials science and research.
- Rotating chairmanship of the TAG and GB.

2.2.5 Cross-cutting Activities

Cross-cutting activities are aimed at extending the value of JEEPs and the acquired data beyond the value of just the data itself. These activities are, therefore, not directly related to data gathered on specific fuels, claddings, or structural materials. Cross-cutting activities are appropriate to be addressed at the GB and TAG levels, including NEA staff and working parties' involvement, and may extend across several individual JEEPs. Such cross-cutting activities consist of items such as the following:

- **<u>Data preservation and quality assurance:</u>**
  Due to the nature of FIDES-II, irradiation experiments and PIE will be conducted in multiple facilities located in multiple countries and will be conducted by multiple organizations. As a result, care must be taken to ensure that the collected data is preserved and quality-assured in a manner such that it may be used by other member organizations – both now and in the future. This also requires ensuring data consistency and curation between different laboratories, especially considering the importance that the use of data-driven, machine learning-based techniques is increasingly acquiring. It is generally considered within the FIDES-II membership

that much of this effort will be addressed organically through the regular “peer-review” of the JEEPs within FIDES-II. However, in the future it could be envisioned that resources are dedicated specifically to data preservation and quality assurance activities.

- **Training, education, and dissemination of results:**
  There is a need to collect data through irradiation experiments within the FIDES-II framework, since the needed data is currently not available. As such, data collected through irradiation experiments and PIE within FIDES-II will inevitably add to the scientific body of knowledge. There is a responsibility to the FIDES-II community and the scientific community in general to share these additions to the scientific body of knowledge with the scientific community (within the constraints of the FIDES-II agreement, and other Intellectual Property agreements). Sharing of data/research is in the interest of FIDES-II members to inform continued research within FIDES-II, to demonstrate the value of the framework to funding bodies, and to build and maintain relevant competence throughout the sector and among young scientists. Not only should publications and reports be issued as appropriate within the various JEEPs, but training and education should also be offered to FIDES-II members and non-FIDES-II members, where appropriate. This can be accomplished e.g., in the form of HRP-style Summer Schools. A partnership with the Nuclear Education, Skills and Technology (NEST) Framework is also envisioned to add structure and visibility to FIDES-II training and education activities. In the future it could be envisioned that resources are dedicated to support training and education activities.

- **Know-how**
  It is in the interest of FIDES-II to ensure that members, across their various facilities, have sufficient know-how to design, fabricate, conduct, and analyse irradiation experiments and PIE. In this document, *Know-how* is distinguished from the *Training, education, and dissemination of results* bullet above, in that *know-how* pertains to the practices for execution of experiments and PIE, whereas *Training, education, and dissemination of results* pertains mainly to dissemination and use of scientific results from the JEEPs. Notwithstanding, maintaining know-how among the FIDES-II members could e.g., be carried out through establishment of best practices for various activities, and may also include training activities e.g. for those that design and/or operate experimental systems. Securing know-how within the community is exemplified by the DEVICE group and may also be advanced through NEST fellowships.

3 Referencing the Strategic Plan in Proposals

The existing guidelines for proposing JEEPs within FIDES-II are given in [27]; however, this document pre-dates FIDES-II (and in fact also FIDES). It is expected that this document will either be updated or replaced with a specific document for FIDES-II that contains updated guidelines for proposing JEEPs and other activities as well as guidance for the TAG and GB for evaluating proposals. Future proposals should reference the strategic objectives described in this document. To facilitate referencing this document, a numbered list, corresponding to the strategic and framework objectives, is provided in Appendix C.

A common goal of FIDES-II activities is filling in known and anticipated gaps in experimental and theoretical knowledge on fuel behaviour and material properties under irradiation. Quantification and comparison of the need in certain data may become a challenging task for decision-making. For instance, some type of index of importance can be used by core groups when proposing JEEPs (e.g. based on a PIRT [28]), or independently by TAG and/or GB, as a way to quantify the importance.

For the time being, when addressing important topics, the portfolio of the HRP experiments may be taken as a starting point of what is FIDES-II trying to achieve. However, great care must be taken since not everything was possible in the Halden reactor and some studies were not performed there for technical reasons, thus it does not mean there was no need for particular experiments just because they weren't performed in Halden. For example, the IFA-650 LOCA test series was designed to investigate the effect of the fuel relocation within the rod on cladding temperature and oxidation in the ballooned region and secondary hydriding of the rod. As such, the experiment was designed as a single rod experiment with large space around the rod and the temperature history corresponding only to a later part of a PWR/VVER/BWR LOCA event and lacking a capability for post-test examination of the significant amount of fuel dispersed through the cladding rupture. Current and future needs might be different, for example bundle tests or tests focused on the period following the full LOCA transient history, e.g., for quantification of the dispersed fuel state, might be more important for understanding the Fuel Fragmentation, Relocation, and Dispersal (FFRD) phenomenon.

4 References

[1] FIDES-II Agreement

[2] OECD Report 2018 "State-of-the-Art Report on Light Water Reactor Accident-Tolerant Fuels"

[3] Nuclear Fuel Safety Criteria Technical Review (second edition), ISBN 978-92-64-99178-1, OECD 2012.

[4] Nuclear Fuel Behaviour in Loss-of-coolant Accident (LOCA) Conditions: State-of-the-art Report, ISBN 978-92-64-99091-3, NEA No. 6846, OECD 2009.

[5] State of the Art Report on Nuclear Fuel Behaviour in Loss-of-Coolant Accident (LOCA) Conditions, Update and Revision of the Report NEA No. 6846. (restricted to OECD/NEA CSNI WGFS members)

[6] LOCA Criteria Basis and Test Methodology, CSNI Technical Opinion Papers No. 13, NEA No. 6986, OECD 2011.

[7] Report on Fuel Fragmentation, Relocation and Dispersal (FFRD). NEA/CSNI/R(2016)16, OECD 2016.

[8] State-of-the-art Report on Nuclear Fuel Behaviour Under Reactivity-initiated Accident Conditions. NEA No. 7575, OECD 2022.

[9] Applicability of Nuclear Fuel Safety Criteria to Accident-Tolerant Fuel Designs. CSNI Technical Opinion Paper No. 19. NEA No. 7576, OECD 2022.

[10] Leaking Fuel Impacts and Practices. NEA/CSNI/R(2014)10, OECD 2014.

[11] Nuclear Safety Research Support Facilities for Existing and Advanced Reactors: 2021 Update, OECD 2021

[12] Martin L. Grossbeck, 1.05 - Effect of Radiation on Strength and Ductility of Metals and Alloys, in: Comprehensive Nuclear Materials (Second Edition), Editor(s): Rudy J.M. Konings, Roger E. Stoller, Elsevier, 2012, 130-152, https://doi.org/10.1016/B978-0-08-102865-0.00004-2.

[13] Peter L. Andresen and Gary S. Was, 4.07 - Irradiation Assisted Stress Corrosion Cracking, in: Comprehensive Nuclear Materials (Second Edition), Editor(s): Rudy J.M. Konings, Roger E. Stoller, Elsevier, 2019, 190-217, https://doi.org/10.1016/B978-0-08-102865-0.00111-4.

[14] Serena Bassini, Sebastiano Cataldo, Carlo Cristalli, Angela Fiore, Camillo Sartorio, Mariano Tarantino, Marco Utili, Paolo Ferroni, Michael Ickes, Alessandro Alemberti, Michele Frignani, 4.08

- Material Performance in Lead and Lead-Bismuth Alloy, in: Comprehensive Nuclear Materials (Second Edition), Editor(s): Rudy J.M. Konings, Roger E. Stoller, Elsevier, 2020, 218-241, https://doi.org/10.1016/B978-0-12-803581-8.00749-9.

[15] Yoonjo (Jo Jo) Lee, 4.09 - Material Performance in Molten Salt, in: Comprehensive Nuclear Materials (Second Edition), Editor(s): Rudy J.M. Konings, Roger E. Stoller, Elsevier, 2020, 242-265, https://doi.org/10.1016/B978-0-12-803581-8.00750-5.

[16] Richard N. Wright, Jill Wright, Celine Cabet, 4.10 - Material Performance in Helium-Cooled Systems, in: Comprehensive Nuclear Materials (Second Edition), Editor(s): Rudy J.M. Konings, Roger E. Stoller, Elsevier, 2019, 266-291, https://doi.org/10.1016/B978-0-08-102865-0.00114-X.

[17] Todd R. Allen, Y. Chen, X. Ren, K. Sridharan, L. Tan, Gary S. Was, E. West, D. Guzonas, 4.11 - Material Performance in Supercritical Water, in: Comprehensive Nuclear Materials (Second Edition), Editor(s): Rudy J.M. Konings, Roger E. Stoller, Elsevier, 2012, 292-338, https://doi.org/10.1016/B978-0-08-102865-0.00115-1.

[18] Meimei Li, Krishnamurti Natesan, Wei-Ying Chen, 4.12 - Material Performance in Sodium, in: Comprehensive Nuclear Materials (Second Edition), Editor(s): Rudy J.M. Konings, Roger E. Stoller, Elsevier, 2020, 339-356, https://doi.org/10.1016/B978-0-12-803581-8.11753-9.

[19] Arunodaya Bhattacharya and Steven J. Zinkle, 1.12 - Cavity Swelling in Irradiated Materials, in: Comprehensive Nuclear Materials (Second Edition), Editor(s): Rudy J.M. Konings, Roger E. Stoller, Elsevier, 2020, 406-455, https://doi.org/10.1016/B978-0-12-803581-8.11599-1.

[20] Fabien Onimus, Thomas Jourdan, Cheng Xu, Anne A. Campbell, Malcolm Griffiths, 1.10 - Irradiation Creep in Materials, in: Comprehensive Nuclear Materials (Second Edition), Editor(s): Rudy J.M. Konings, Roger E. Stoller, Elsevier, 2020, 310-366, https://doi.org/10.1016/B978-0-12-803581-8.11645-5.

[21] Wolfgang Hofflener, Damage assessment in structural metallic materials for advanced nuclear plants, J. Mater. Sci. (2010) 45, 2247–2257, DOI 10.1007/s10853-010-4236-7.

[22] K. Lindgren, M. Bjurman, P. Efsing, M. Thuvander, Integrated effect of thermal ageing and low flux irradiation on microstructural evolution of the ferrite of welded austenitic stainless steels, Journal of Nuclear Materials (2021) 551, 152967,https://doi.org/10.1016/j.jnucmat.2021.152967.

[23] W.G. Wolfer, 1.01 - Fundamental Properties of Defects in Metals, in: Comprehensive Nuclear Materials (Second Edition), Editor(s): Rudy J.M. Konings, Roger E. Stoller, Elsevier, 2020, 1-49, https://doi.org/10.1016/B978-0-08-102865-0.00001-7.

[24] Shradha Agarwal, Steven J. Zinkle, 1.03 - Experimental Studies on Primary Damage Formation, in: Comprehensive Nuclear Materials (Second Edition), Editor(s): Rudy J.M. Konings, Roger E. Stoller, Elsevier, 2020, 74-90, https://doi.org/10.1016/B978-0-12-803581-8.11597-8.

[25] Steven J. Zinkle, 1.04 - Radiation-Induced Effects on Microstructure, in: Comprehensive Nuclear Materials (Second Edition), Editor(s): Rudy J.M. Konings, Roger E. Stoller, Elsevier, 2020, 91-129, https://doi.org/10.1016/B978-0-12-803581-8.12075-2.

[26] Maylise Nastar, Frédéric Soisson, 1.08 - Radiation-Induced Segregation, in: Comprehensive Nuclear Materials (Second Edition), Editor(s): Rudy J.M. Konings, Roger E. Stoller, Elsevier, 2020, 235-264, https://doi.org/10.1016/B978-0-12-803581-8.00668-8.

[27] NEA Framework for Irradiation Experiments (FIDES-II): Proposal for Basic Principles and Operating Procedures

[28] Phenomena Identification and Ranking Table. R&D Priorities for Loss-of-Cooling and Loss-of-Coolant Accidents in Spent Nuclear Fuel Pools. NEA/CSNI/R(2017)18, OECD 2018

Appendix A

Appendix A, Data Needs for Nuclear Fuel and Cladding

Operating Conditions / Experiment type	Type of data needed	Current Fuels and LWR SMRs	Near-term New Fuels	Advanced Fuels
LOCA	Effects of fuel state on fuel dispersal, particularly, during a LOCA, e.g., conditions related to burnup, pellet-cladding bonding, properties affected by pre-transient power, pressure, and volume of the entraining gas, etc.	x	x	
	Ballooning, embrittlement, burst.		x	
LOCA/RIA	MOX behaviour.	x		
	Fuel fragmentation, relocation, dispersal.	x	x	
	Effects of axial distribution of gas pressure in fuel rods in consideration of transient fission gas release and restricted axial gas flow.	x	x	
	Effects of fuel doping (by burnable absorbers, like Gd, or chromium and/or aluminium additives) on fuel rod behaviour.	x	x	
LOCA/RIA/power ramp	Fuel to coolant interaction.	x	x	
	Fission Gas Release.		x	
	Behaviour of the cladding coating		x	
RIA	Post-DNB behaviour, including cladding ballooning and burst, as well as high temperature oxidation-induced failure.	x	x	
	Post-failure behaviour, including fuel relocation and dispersal, as well as Fuel-to-Coolant Interaction.	x	x	
	Cladding failure by PCMI.		x	
PCI/PCMI	Effects of localized crud deposition and/or oxidation on PCMI/PCI failure limits of the cladding.	x	x	
	Axial and diametral cladding loading (stress- and strain bi-axiality), fuel to cladding contact conditions.	x	x	
	Fuel chemistry and corrosion fission products behavior.	x	x	
	Performance to SCC-PCI failure		x	

Appendix A

Operating Conditions / Experiment type	**Type of data needed**	Current Fuels and LWR SMRs	Near-term New Fuels	Advanced Fuels
Base Irradiation and Anticipated Operational Occurrences	Behaviour under more demanding conditions, e.g., basic properties in normal and off-normal conditions, including changes of thermophysical and mechanical fuel and cladding properties with irradiation, at higher temperature, stress, strain rate and irradiation dose, etc.	x		
	Basic properties of new fuels in normal and off-normal conditions, viz.: Fuel: • Temperature, fission gas retention and release, internal pressure. • Microstructural evolution under irradiation (fuel densification and swelling, cracking, recrystallization, etc.). • Stress – free dimensional changes (e.g., densification and sintering), dimensional changes under loading (e.g., creep). • Changes of thermophysical and mechanical properties with irradiation, including thermal conductivity, thermal diffusivity, specific heat, and coefficient of thermal expansion (up to or near the fuel melting point), yield stress, creep rate (irradiation induced creep and thermal creep), fracture toughness, elastic moduli. • Chemistry, migration, and release of volatile fission products. Cladding: • Stress – free dimensional changes (irradiation growth), as well as dimensional changes under loading (creep). • Interaction with the coolant (corrosion, hydrogen pickup and migration, hydride re-orientation, stress corrosion cracking) • Creep, growth, and swelling, behavior of the coating, • Microstructural evolution under irradiation • Mechanical and chemical interaction between fuel and cladding materials under irradiation		x	
Base irradiation, AOO, DBA, BDBA	Failure mechanisms and analytical limits, including Effects of power maneuvering (e.g., load-follow operation) on cladding failure, including new cladding materials.			x

Appendix B

Appendix B, Data needs for Structural Materials

LWR or *Advanced reactors (=AR)*	**MATERIALS →** **Properties/phenomena ↓**	Ni-based alloys	Low alloy Steels	Stainless Steels	Advanced Materials
LWR / AR	Irradiation hardening and embrittlement (<400ºC) • Evaluation and prediction of fracture toughness and ductile-brittle transition temperature in RPV low alloy steels (especially low flux/high dose, i.e. > 0.2 dpa) • Loss of ductility under irradiation in austenitic stainless steels (not for all steels, only for those not codified yet) • Low temperature embrittlement and loss of uniform elongation in Fe-9-14%Cr steels up to tens of dpa • Irradiation effects on strength, ductility, and fracture toughness of additively manufactured (AM) steels and nickel alloys		x	x	x
LWR / AR	IASCC: Evaluation of crack growth rate, initiation condition and water chemistry under irradiation (in supercritical water in the case of SCWR) • Comparison with similar results in primary PWR water chemistry without irradiation or after irradiation • Static and transient mechanical loading	x		x	x
LWR / AR	Void swelling • 3xx series for GenIII up to tens of dpa, especially at relatively low flux • 15-15Ti for AR up to 120 dpa • Ni-based alloys up to high dose (tens of dpa) with He production due to transmutation (especially under non-CANDU conditions)	x		x	x
LWR / AR	Long-term thermal ageing of austenitic stainless steel base material and welds under mild (< 1 dpa) irradiation (also for Na-cooled AR)			x	x
LWR / AR	Radiation effects on corrosion fatigue			x	
LWR / AR	Irradiation creep and creep-fatigue / stress relaxation under irradiation • 3xx series for GenIII, up to 120 dpa, 350-400ºC or higher • F/M and alumina forming steels for GenIV, similar conditions as above			x	x

Appendix B

LWR or *Advanced reactors (=AR)*	**MATERIALS →** **Properties/phenomena ↓**	Ni-based alloys	Low alloy Steels	Stainless Steels	Advanced Materials
LWR / AR	Microstructure evolution:[4] • Evolution of radiation defects up to relevant dpa in any material/condition • Radiation induced segregation (RIS) at radiation and extended defects in low alloy steels (round 300ºC especially at low flux/high dose, i.e. > 0.2 dpa) and austenitic steels (at 350-400ºC or higher, up to tens of dpa) • Precipitation of γ'' in Ni alloys in a wide range of temperatures and dpa • Stability of corrosion-protecting layers (coatings or self-healing) versus temperature and dpa in F/M and austentic stainless steels	x	x	x	x
AR	Synergy between irradiation and corrosion/dissolution/erosion in non-aqueous environments • In Na : 15-15 Ti stainless steels, ODS F/M steels • In liquid Pb and relevant liquid alloys (e.g. PbBi eutectic): 15-15 Ti stainless steels and coated version, coated and uncoated F/M steels, alumina forming steels (AFA and FeCrAl) • In He with impurities: 15-15 Ti stainless steels, Ni-based alloys • In molten salt: Ni-based alloys, SIC$_f$/SIC, coated materials	x		x	x
AR	Fast spectrum, high temps, with He production o For unloaded and creep/stress relaxation	x			

---

[4] Note that this entry does not necessarily refer to bespoke experiments, but to the need of foreseeing microstructure examination specimens in experiments dedicated to other issues. In addition, often the bottleneck in these experiments is not only, or not really, the irradiation, but rather the fact that post-irradiation microstructural characterization is a costly and time-consuming activity, which sometimes requires several years before being concluded, or ends up not being concluded.

Appendix B

LWR or *Advanced reactors (=AR)*	**MATERIALS →** **Properties/phenomena ↓**	Ni-based alloys	Low alloy Steels	Stainless Steels	Advanced Materials
AR	HTGR/GFR • Carbon and SiC Composites: ○ Radiation induced embrittlement : evolution of pseudo-ductility versus dose and temperature ○ Fatigue crack initiation and growth of carbon under irradiation in helium with impurities or supercritical CO_2 environments. ○ Irradiation effects on the microstructure of graphite, and interphase stability, especially under higher irradiation temperatures (up to 900°C) ○ Composite architecture stability under irradiation (e.g., effect of differential fiber-matrix swelling) ○ Leak-tightness under irradiation ○ Thermal properties (thermal expansion, conductivity, etc.) versus radiation dose • Graphite (grades on interest) ○ Irradiated properties of per ASME Code Sec. III Div. 5. Molten Salt • Graphite (grades on interest) ○ Irradiated properties per ASME Code Sec. III Div. 5., salt infiltration				x

Appendix C

Appendix C, Numbered List of Objectives to Reference in Proposals

Research Objectives:

1) Motivations
    a) Support of operation
    b) Support fuel qualification
    c) Support licensing of nuclear fuels
2) Research Subjects
    a) Nuclear Fuel and Cladding
        i) Current Fuel (see table 1)
        ii) Near-term New Fuels (see table 1)
        iii) and Advanced Fuels (see table 1)
    b) Structural Materials and Manufacturing Processes
        i) Current Materials (currently used in LWRs)
        ii) Near-term New Materials (e.g. for use in current NPPs or near-term SMR applications)
        iii) Advanced Materials (for use in future NPPs including Advanced Non-LWR (ANLWR) Reactors)
3) Research Objectives
    a) Nuclear Fuel and Cladding
        i) Fundamental properties under irradiation
        ii) Fuel and cladding performance under steady-state conditions
        iii) Response to power events
        iv) Response to Loss of Coolant Accidents
        v) Response to Reactivity Insertion Accidents
        vi) Response of failed fuel rods to transients
    b) Structural Materials and Manufacturing Processes
        i) Irradiation hardening and embrittlement
        ii) Irradiation assisted stress corrosion cracking (in water)
        iii) Synergy between irradiation and corrosion/dissolution/erosion in non-aqueous environments
        iv) Radiation-induced swelling
        v) Radiation-induced creep
        vi) Radiation-enhanced stress relaxation
        vii) Synergy between irradiation and fatigue/creep-fatigue
        viii) Combined effect of mild irradiation and thermal ageing
        ix) Microstructural and microchemical evolution under irradiation (e.g., defect production, solute clusters and precipitates, radiation induced segregation, etc.)

Framework Objectives:

1) Maintaining and Developing Capabilities: Ensuring relevant irradiation and PIE facilities and experimental capabilities are maintained and developed, such that they are available to the FIDES-II framework when needed.
2) Size and Composition of Experimental Program: The number and mix of experiment types to be performed should ensure that members obtain sufficient value in return for their membership contributions to the framework and should be sufficient to attract and maintain a robust membership community.
3) Size and Composition of FIDES-II Framework: The number and type of framework members affects the potential scope and value of the experimental program, e.g., via the available budget, facilities, and expertise.
4) Community Building: Building and fostering a robust community promotes collaboration, and thus enhances the value of experiments, which in-turn encourages continued participation and aids in attracting new members.
5) Cross-cutting Activities: Extending the value of JEEPs and acquired data beyond the value of just the data itself, e.g., modeling tools assessment, training and education, data preservation, etc.