**Technical Report on Synergies in Technology Development between Nuclear Fission and Fusion for Energy Production**

**Section 3: Technology and 3S areas for synergies and technology and know-how transfer**

Outline of Chapter 3.2: “Structural Materials and Circulating Fluids”

3.2.1 Neutron irradiation resistant materials (Ermile Gaganidze, KIT, who may know others for subsections)

3.2.1.1 Qualification and codification of ferritic-martensitic steels up to high dose (100 dpa)

a) Mechanical property data and mechanical behaviour rules of base material

- Low temperature embrittlement and plastic flow localization

- High temperature He embrittlement (*especially for fusion, less of an issue for fission*)

b) Swelling behaviour data in presence of transmutants (*especially for fusion, less of an issue for fission*)

c) Irradiation creep data and rules

3.2.1.2 Qualification and codification of ferritic-martensitic steel welds, as-received and under irradiation

*(similar topics as above)*

3.2.1.3 Development of methodologies to predict the behaviour of F/M steels under irradiation (for codification and design purposes)

a) Microstructure evolution (modelling and advanced characterization) versus irradiation dose: defect evolution, precipitation and segregation, processes leading to swelling (LM: I can write this)

b) Macroscopic changes: radiation-induced embrittlement, swelling, irradiation creep versus irradiation dose (if he wasn’t sick and also unable to be concise, Maxime Sauzay could do this … but … who else?)

3.2.1.4 Development of advanced methodologies for non-destructive continuous materials health monitoring versus dose

3.2.1.5 Use of ion/proton irradiation to emulate neutron irradiation (LM I can write this, with the help of C. Kaden of HZDR)

3.2.1.6 *(other topics?)*

3.2.2 Temperature and load cycle stable materials (Jean Henry, CEA, , who may know others for subsections)

3.2.2.1 Oxide dispersion strengthened steels

a) Development of industrially upgradable manufacturing techniques that guarantee property reproducibility

b) Development of industrially upgradable non-fusion welding techniques

c) Modelling of relevance for the two above issues

3.2.2.2 Creep-enhanced resistant steels

a) Identification of compositional tuning and thermo-mechanical treatments to improve creep properties of conventional F/M steels

b) Development of predictive methodologies (thermodynamic modelling, data-driven using artificial intelligence, …) in support of the above task

c) Development of accelerated methodologies for material optimisation (high throughput fabrication, processing, characterization and simulation, focused on high temperature mechanical behaviour), in support of task a)

3.2.2.3 Design rules for cyclic softening (Jarir Aktaa, KIT)

3.2.2.4  *(other topics?)*

3.2.3 Compatibility with circulating fluids and mitigation strategies

3.2.3.1 Protective coatings and permeation barriers (Fabio Di Fonzo, IIT – Marco Utili)

**a) Development of oxide coatings - alumina based coatings and alumina forming and others:**

Ceramic thin films, in particular alumina, appear to be the most suitable protective strategy for structural steels to be used both BB and GIV systems. Two main classes of barrier layers emerged in recent years: coatings and oxide forming alloys. Coatings relay on thin film deposition techniques like Pulsed Laser Deposition, sputtering or Atomic Layer Deposition, or on surface alluminization followed by high temperature oxidation (ECX, GESA). More traditional pack cementation is considered for more massive components with no limitation in terms of high temperature processing, even this does not seem compatible with EUROFER, teh material of choice for ITER and DEMO.  Employing coatings, it is possible to extend the operational lifetime of qualified structural materials shortening, at least in principle, the legthy qualification process of new materials. On the opposite spectrum of solutions alumina forming alloys (AFA) or high entropy alloys rely either on the formation of a protective scale of alumina on the surface of the steel or on an increased stability of entropy stabilized multi principal alloys.

Alumina is naturally inert in contact with Pb, PbBi and Na and resistant to high temperature corrosion in He so it is the perfect candidate for GIV systems. The interaction with PbLi is more complex but the studies reported so far show promising results for several thousands hours of contact time. Reduction of hydrogen isotopes permeation and high electrical resistivity are added benefit of interest for BB applications.

**b) Upscaling of coating technologies to meet industrial demands**

Any coating technique must be able to coat, at minimum, tubes with lengths from 2 to 4 m long, since these are the typical lengths envisioned as fuel cladding in Pb/PbBi fast reactors and water tubes in WCLL and HCLL BB designs. This seems achievable by most of the coating techniques currently studied. A more difficult task is the coating of complex components like the internals of a fission reactor or of the welds of a BB module.

In this case a self limiting, chemical vapor deposition like ALD seems more suitable even if further studies are needed. In any case, the development of post deposition quality assurance methods is mandatory for all coatings techniques.

**c) Development of predictive methodologies in support of the above tasks**

**d) Development of accelerated methodologies for material optimisation (high throughput fabrication, processing, characterization and simulation, targeting corrosion resistance), in support of tasks a) and b)**

**e) Development of suitable frameworks for coating qualification in nuclear environments**

Coating qualification in nuclear environments is of paramount importance and at the moment no significant data are available. Exposure of coated steels and new alloys to thermal and fast spectrum neutrons with strict control of irradiation temperature is key for fast development and qualification of existing and new coatings. Given the complexity of in reactor experiments and the complete lack of data, exposure of coated samples in inert gas filled capsules should be the first target, followed by combined irradiation/corrosion/permeation experiments.

3.2.3.2 Corrosion resistant materials (Alfons Weisenburger and Adrian Jianu, KIT)

a) Development of (F/M) steels that form self-healing protective coatings, e.g. FeCrAl (*especially for fission, for fusion this solution raises problems of activation*) (include Peter Szakalos, KTH)

b) Development of (low activation) high entropy alloys with high corrosion (but also radiation and temperature …) resistance

c) Development of predictive methodologies (thermodynamic modelling, data-driven using artificial intelligence, …) in support of the above tasks (include Isaac Toda?)

c) Development of accelerated methodologies for material optimisation (high throughput fabrication, processing, characterization and simulation, targeting corrosion resistance), in support of tasks a) and b)

3.2.2.3 Fluid handling and purification (Marco Utili, ENEA)

1. Experimental validation of purification systems, especially cold traps for fission and fusion relevant fluids: this includes the characterization of the best operative conditions in terms of impurity concentration (indeed, mass transport is fostered by a large concentration gradient, thus it should be possible to find an optimal concentration for the system).
2. Dimensioning of the purification systems and integration in the reactor.
3. Numerical modelling of mass transport and activation of corrosion products. This point will also support the development of point a) and b).
4. Development of instrumentation in order to be able to characterize the systems and to monitor the change in the operative conditions.