GEN IV International Forum
Expertise | Collaboration | Excellence

Interactions between Sodium and Fission Products in Case of a Severe Accident in a Sodium-cooled Fast Reactor

Summary / Objectives:

An overview of severe accident scenarios in Sodium-cooled Fast Reactors will be presented, focusing on the thermochemistry aspects and how the CALPHAD method could be used to enhance the prediction of the different phases that could form depending on the conditions of the system. CALPHAD, which stands for CALculation of PHAse Diagram, is a semi-empirical method that enables to develop a thermodynamic model based on the Gibbs free energy of the gas, liquid and solid phases as a function of temperature, pressure and composition of the system. Experimental measurements of the thermodynamic properties of some fission product compounds formed in the Joint Oxide Gain after interaction with sodium will be presented. These data will be used as input for the thermodynamic modeling.

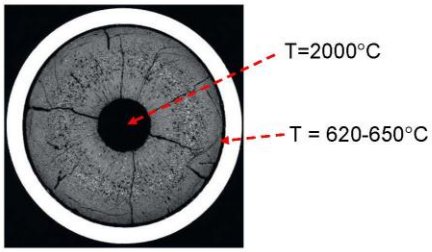
Meet the Presenter:

Mr. Guilhem Kauric is a second year PhD student at CEA Saclay in the "Service de la corrosion et du comportement des matériaux dans leur environnement" (SCCME) in the "Laboratoire de Modelisation de Thermodynamique et de Thermochimie (LM2T)". His PhD research aims at investigating the chemical interactions between MOX fuel, fission products and sodium for the safety assessment of the Sodium-cooled Fast Reactor in case of severe accident. As the chemical system contains many elements, the CALPHAD method approach is the most suitable to develop a model for this study. His research activities, funded by CEA and the ENEN + program, are based on a multidisciplinary approach combining experimental work and modelling. In 2017, he graduated from Chimie Paristech ENSCP (diplome d'ingenieur option chimie des materiaux) and from INSTN with a Master's Degree in Nuclear Engineering option Fuel Cycle.

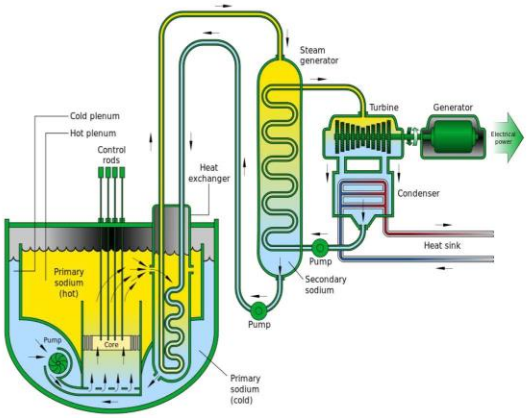
The target is mixed oxide fuel, which is the fuel of SFR.
The mixed oxide fuel is in the cladding as a fuel pellet and the cladding is cooled by liquid metal sodium.

Sodium-cooled Fast Reactors

- Mixed Oxide Fuel $(U_{1-x},Pu_x)O_2$
  - $x > 0.2$
- Pellet restructuring under irradiation



Transversal macrograph of a fuel pin after irradiation in a SFR (2)



Sketch of a Sodium-cooled Fast Reactor (1)

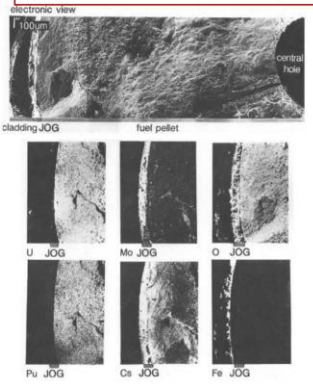
(1) A Technology Roadmap for Generation IV Nuclear Energy Systems, Issued by the U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum, (2002)
(2) J. GUIDEZ, B. BONIN, Réacteurs nucléaires à caloporteur sodium, CEA Saclay; Groupe Moniteur, 2014

5

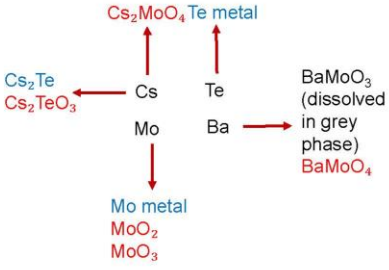
Knowing the stable chemical species produced under irradiation is important, because it affects the assessment of the accident. In addition, it is necessary to consider that SFR is characterized by sodium coexistence.

Fission Products Compounds Formed During Irradiation

Main thermodynamic stable phases in the "Joint Oxyde-Gaine" layer

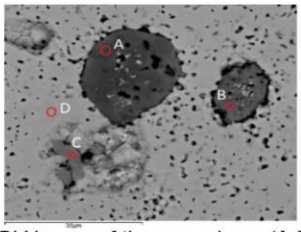


M. Tourasse et al., JNM 188 (1992) 49-57



Main thermodynamic stable phases in the "grey phase"

$(Ba,Sr)(Zr,Mo,U,Pu)O_3$



EDX image of the grey phase (A,B), a Mo-Ru-Pd alloy (C) and the fuel (D)

Simfuel Approaches to Understanding Spent Fuel Behaviour, I.Farnan.

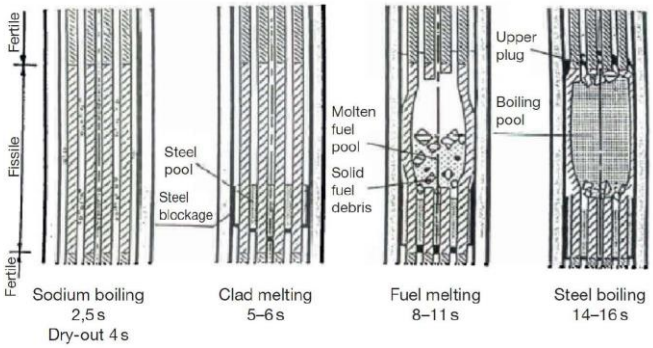
7

Assuming a severe accident, there is an interaction between FP or mixed oxide fuel and sodium. In this study, a thermodynamic study has been carried out focusing on this interaction.

Severe Accident: Definition

- The reactor fuel is significantly **damaged** with more or less extensive **melting of the reactor core**

Phenomena inside the blocked SA



- **Fuel ejection into sodium** or formation of a **local boiling pool** depending on the **scenario**
- Interaction **Na/Fission products compounds**
- Interaction **Na/Mixed Oxide fuel**
- **Volatile fission products** release

J. Papin, Behavior of Fast Reactor Fuel During Transient and Accident Conditions, in: Compr. Nucl. Mater., Elsevier, 2012: pp. 609–634

8

This interaction is different depending on the temperature and oxygen potential, and the stable compounds to be produced will be different. Thermodynamic models that can be applied over a wide range of temperatures and components are needed for severe accident evaluation.

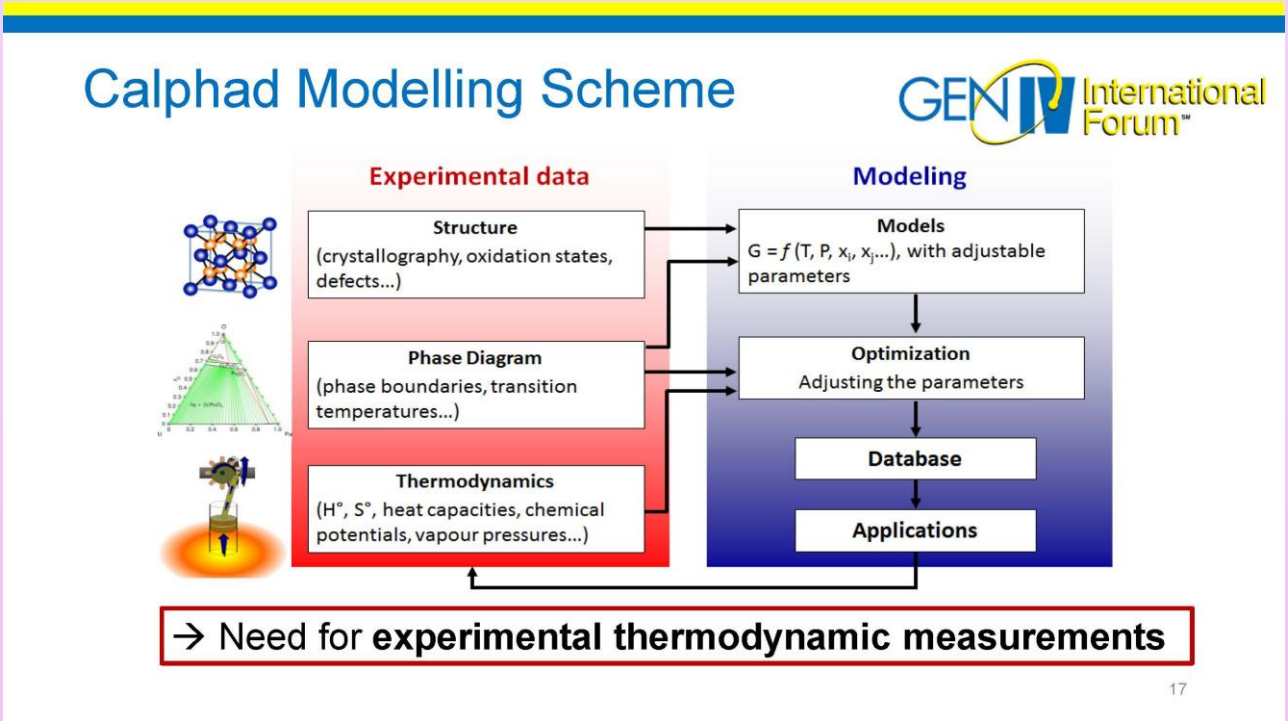
Need for Thermodynamic Modelling

- **Complex** system and **large range of temperatures and compositions**
  - **(Cs-Sr-Ba-I-Te-Mo)-(U,Pu)-O** + interaction with **Na**
- **Thermodynamic model** of the interaction between **fuel**, **fission products** and **liquid sodium** at the **different stages of a severe accident scenario**

Describe the effect of **temperature** and **oxygen potential** on the interaction between sodium and the different fission product compounds

11

Using the Calphad modelling scheme, we can know which compounds are thermodynamically stable. This model requires some experimental thermodynamic data. Prediction accuracy will continue to improve as the data is expanded. The study is being carried out in a multilateral collaboration as The TAFID Database Project.



An example of Cs-Mo-O is presented as an application result of these projects. As a function of their respective compositions, compounds that are stable at a given temperature can be identified. It is very useful for severe accident assessments.