IEM-8 on Strengthening Research and Development Effectiveness in the Light of the Accident at the Fukushima Daiichi Nuclear Power Plant
IAEA, Vienna, 16–20 February 2015

Nuclear safety research in light of the Fukushima-Daiichi accident at the European Commission - Joint Research Centre

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Joint Research Centre – European Commission

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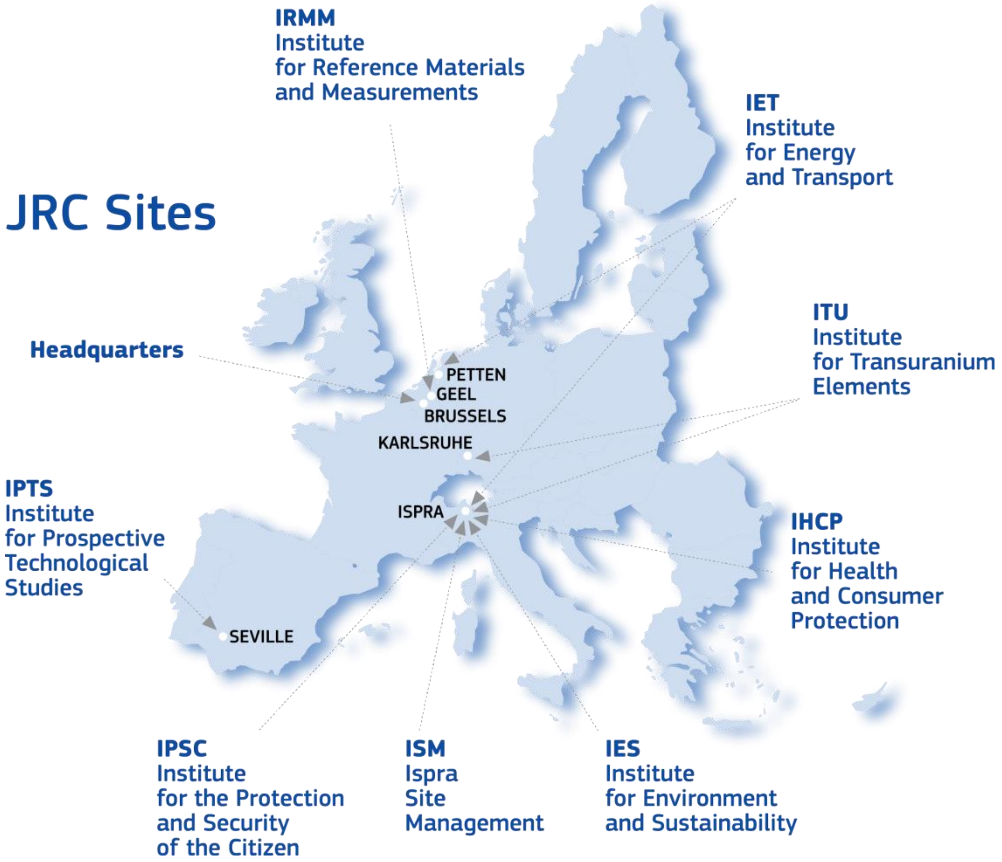
Outline

- Introduction, context
- R&D activities in the JRC after the Fukushima accident
  - Nuclear fuel safety
  - Nuclear reactor safety
  - Reference materials and measurements
- Perspectives



JRC Euratom Programme 2014-2018

European Commission

Basic Research and Applications

Safety of Nuclear Fuels and Fuel Cycles

Safety of Nuclear Reactors

Nuclear Safeguards and Security

Emergency Preparedness and Accident Modelling

Waste Management and Decommissioning

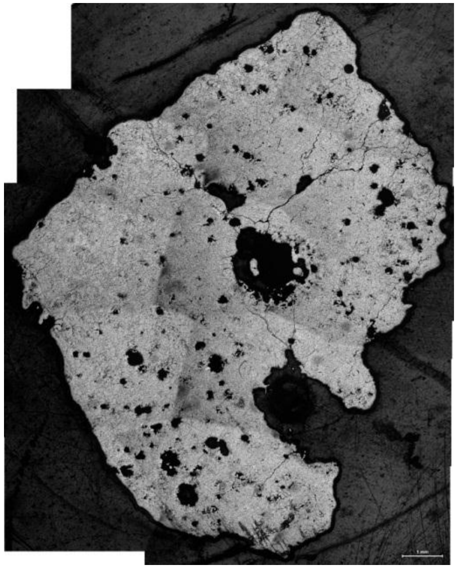
Knowledge Management, Training and Education

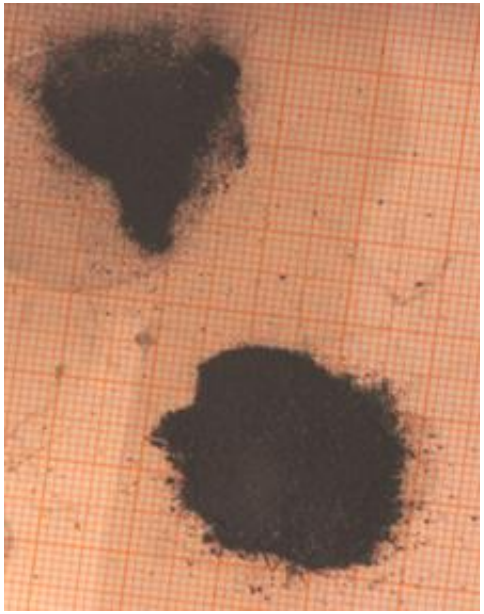
Joint Research Centre

Fuel, corium debris studies

- Source term for radionuclide release.
- Corrosion in seawater and other aqueous media of spent fuel, molten fuel debris.
- Mechanical properties of TMI-2 and other debris to assess retrieval and conditioning options.
- Handling/storage/conditioning of debris; ageing studies.
- Specific aspects of the Fukushima events (BWR, B_4C, ex-vessel interactions,…).
- SAFEST (2014-): JRC leads WP2 on the development of severe accidents research roadmaps

TMI-2 core bore rock samples, after >25 years





Spent fuel leaching in seawater

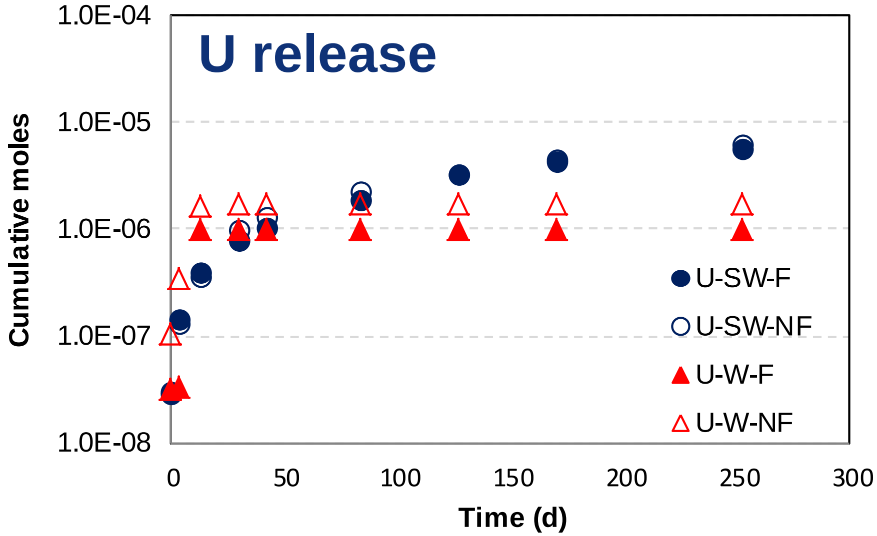
BWR UO_2 54GWd/tHM; de-cladded

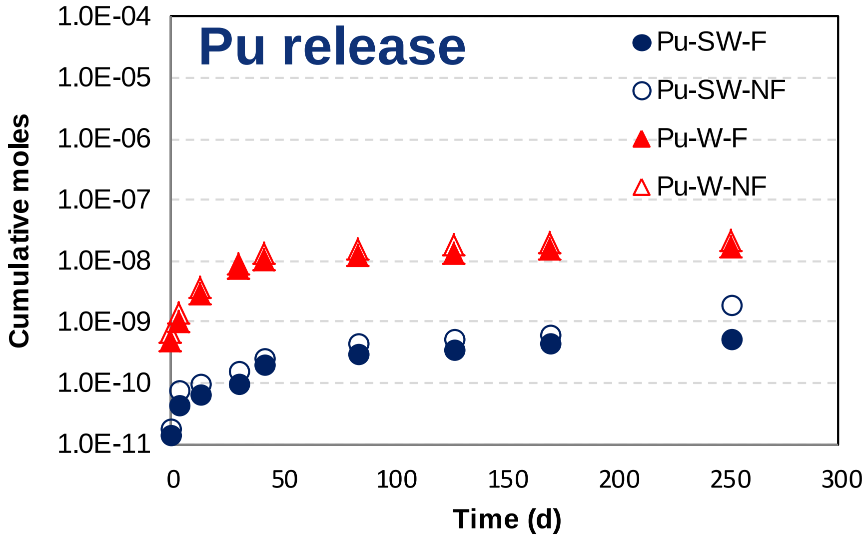
Cumulative mole released as a function of time.

Sequential leaching with total replenishment.

Ongoing: leaching of TMI-2 debris, spent fuel in different cooling media (collaboration with CRIEPI, Japan)

SW: seawater; W: deionized water

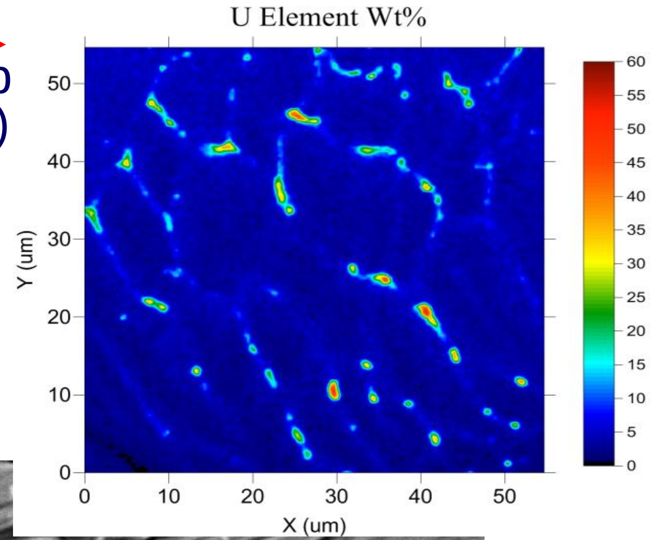




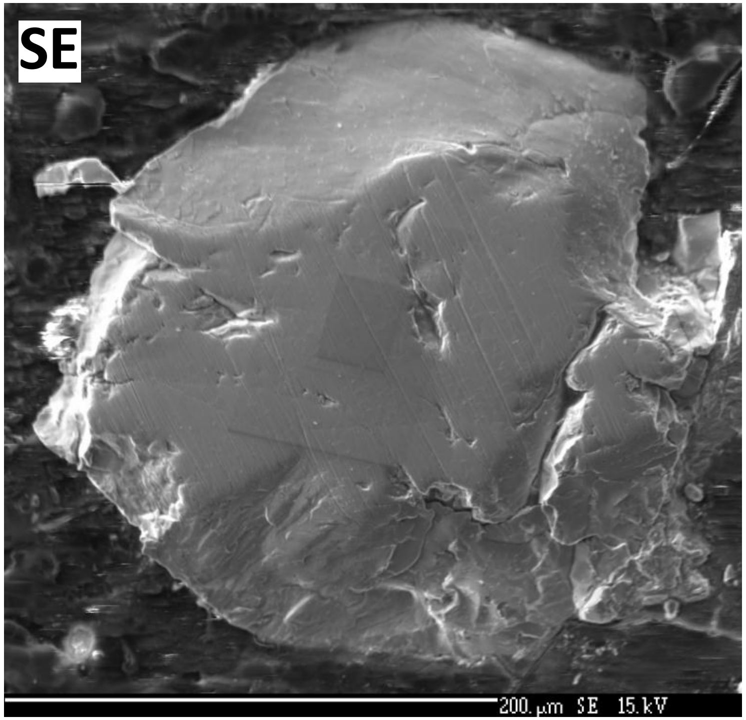
Ex-vessel materials

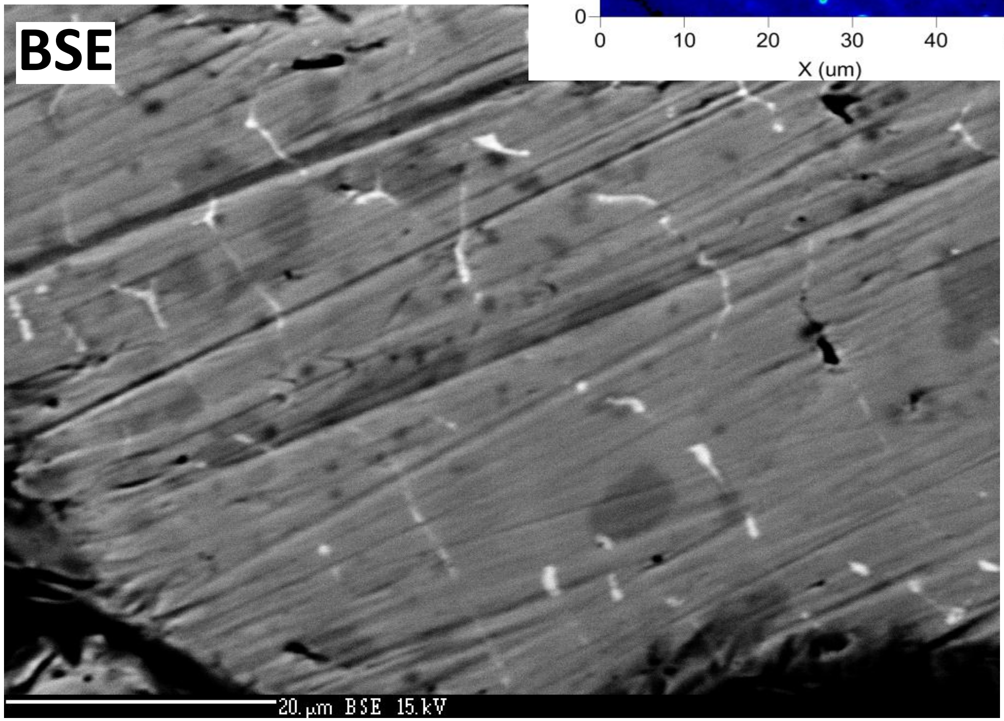
Hot particle from Chernobyl

U map
(EPMA)



metallic Zr particle containing U





Pöml, Burakov et al., 2015

LWR fuel fracturing behaviour

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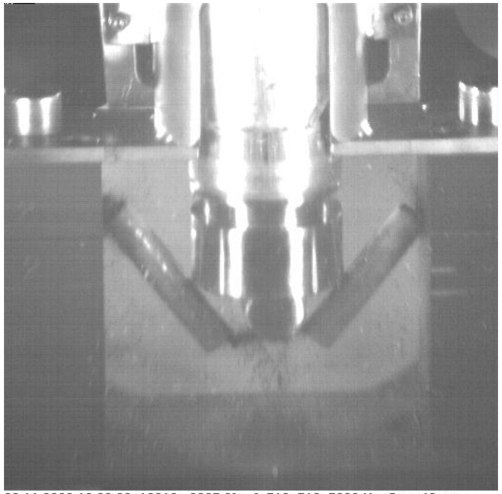
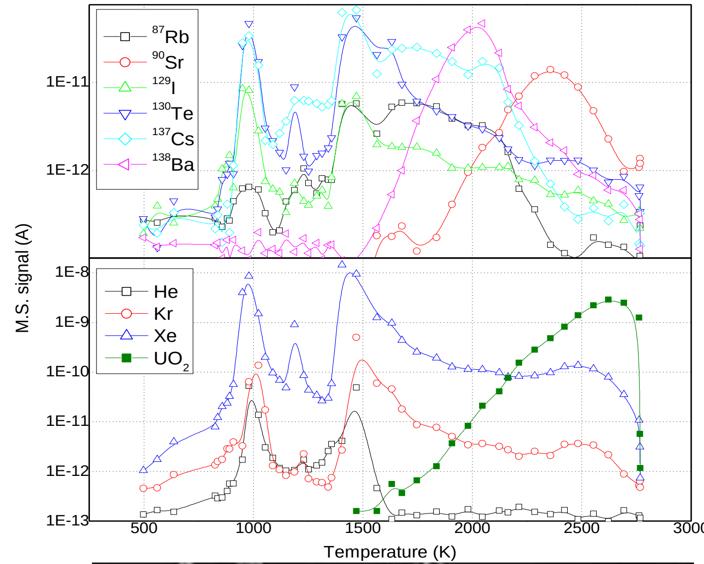
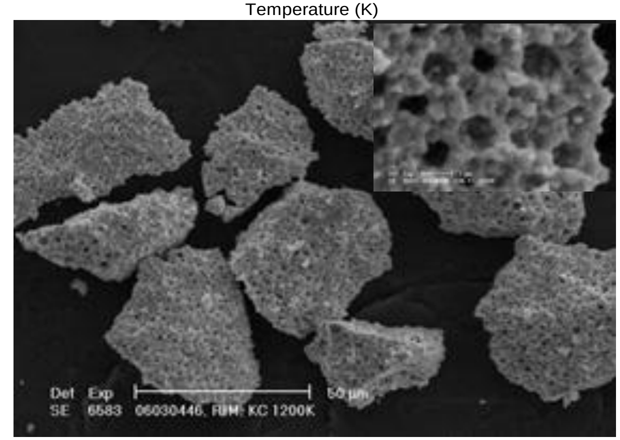

26.11.2008 12:06:03 13312 0205,0[ms] 512x512, 5000 Hz, SpeedCam
MacroVis VLS #00104, V1.9.13

Room temperature impact test, LWR spent fuel rod

Papaioannou et al. 2009 (collaboration with GNS, AREVA);
CRP SPAR III 2014





Thermal fracturing and source term for release:
920 K, UO_2 160 GWd/t (local)

Hiernaut et al., 2008

Nuclear Reactor Accident Analysis and Modelling (NURAM)

European Commission

Severe accident modelling, radiological source term evaluation and accident management of NPPs, in collaboration with EU Member States, Technical Safety Organizations, international organizations, networks…

ASTEC (Accident Source Term Evaluation Code) Reference European code developed by IRSN/GRS for LWR Severe Accident Analyses and Source Term evaluation

→ Collaboration with IRSN for **ASTEC V2 validation**

IRSN INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

GRS Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH

GOBIERNO DE ESPAÑA MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

KIT Karlsruhe Institute of Technology

AEN NEA OECD

Severe Accident Research NETwork of excellence

SARnet

NUGENIA NUclear GENeration II & III Association

IAEA

+ Many others

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International benchmark

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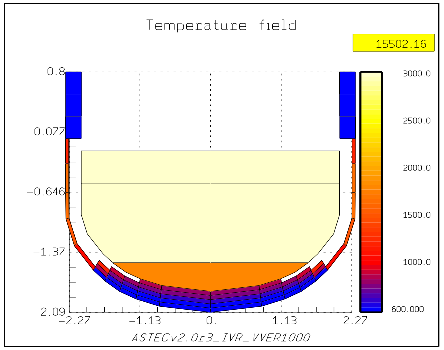
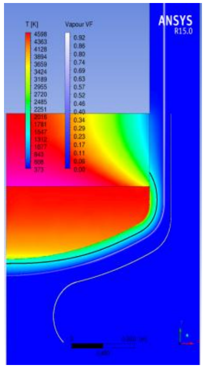
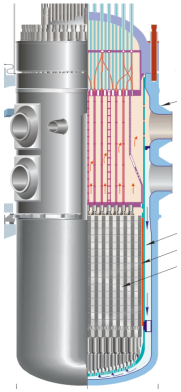
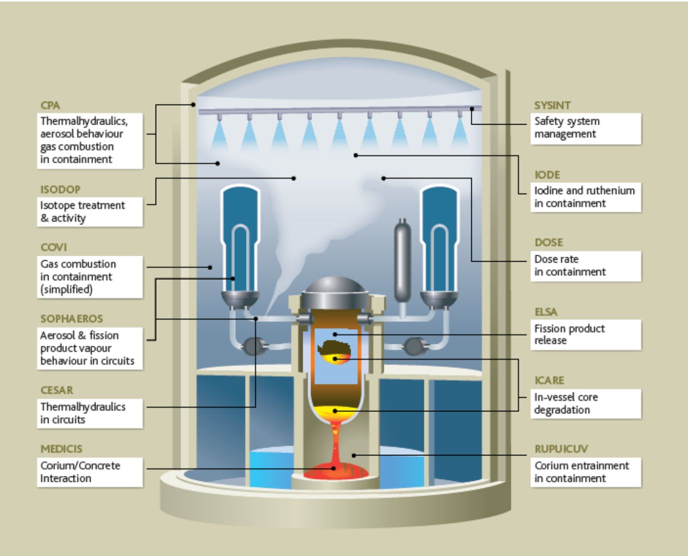
JRC leads an International Benchmark on **“In Vessel Retention for VVER 1000"** (2013-2015)

Calculations performed with **ASTEC V2, MELCOR, MAAP, SOCRAT and CFD codes** by participants **from Czech Republic** (UJV Rez), **Slovakia** (IVS), **Bulgaria** (INRNE, TUS, Kozloduy NPP), **Russian Federation** (KI), **France** (IRSN, CEA, EDF, Areva), **Germany** (USTUTT) and **Finland** (VTT)









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CESAM

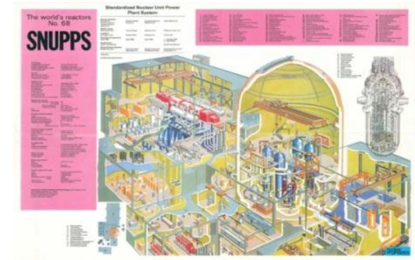
European Commission

EURATOM

cesam

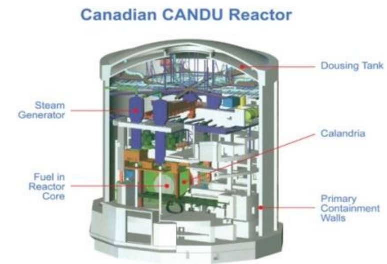
CODE FOR EUROPEAN SEVERE ACCIDENT MANAGEMENT

(2013 – 2017)

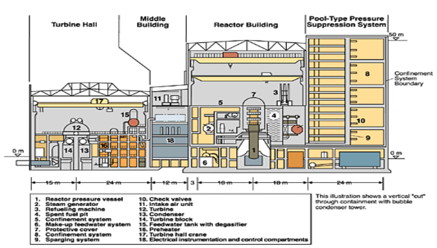


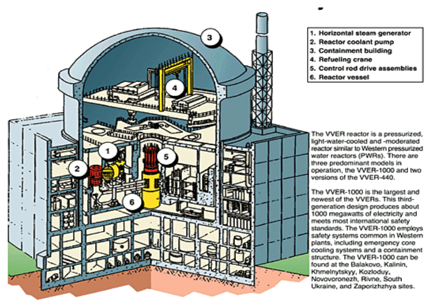
Main objectives:

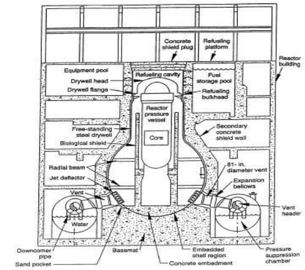
- Enhancement of ASTEC models for Severe Accident Management strategies relevant to Fukushima accident, and associated validation
- Development of "Reference Input decks" and associated documentation for the European NPPs



JRC leads WP40 on Plant Applications and Severe Accident Management







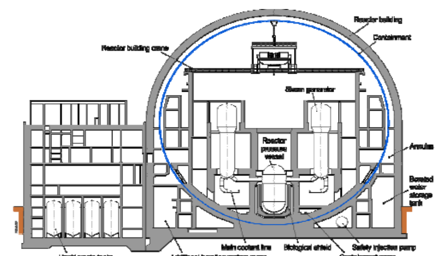


Figure 1-1: Cross-section of a PWR

Neutron Resonance Densitometry to characterize debris of melted fuel

NRD = **NRTA** + **NRCA/PGA**

NRD	NRTA	NRCA/PGA
Characterization of melted fuel	**Quantification of Pu & U-isotopes**	**Identification of other elements**

Feedback for analysis of NRTA data

Resonances can be used as fingerprints to

- identify and quantify nuclides
- elemental (& isotopic) composition

NRTA & NRCA (developed at JRC-IRMM)

- non - Destructive
- no sample preparation required
- negligible residual activation

NRD : Neutron Resonance Densitometry
NRTA : Neutron Resonance Transmission Analysis
NRCA : Neutron Resonance Capture Analysis
PGA : Prompt Gamma-ray Analysis

35th ESARDA 2013
Harada et al., "Proposal of NRD for particle like debris of melted fuel using NRTA and NRCA"

Validation of NRTA

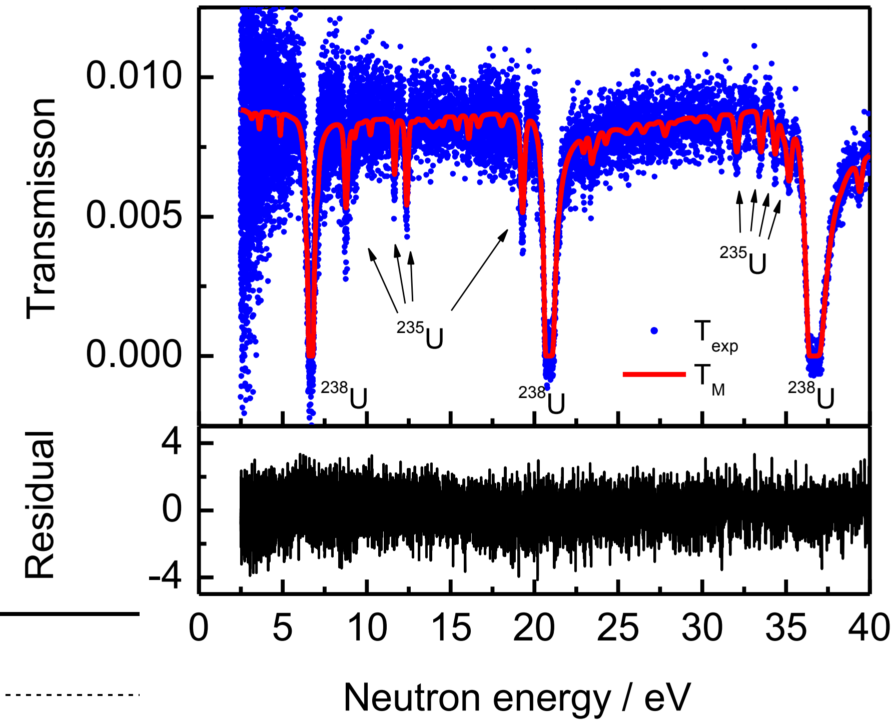
Characterization of U-reference materials

$$T_{exp} = \frac{C_{in}}{C_{out}} \approx e^{-\sum_k n_k \sigma_{tot,k}(E)}$$

$\sigma_{tot,k}$ total cross section (known)

n_k areal number density can be determined = total mass/area

T transmission



U_3O_8 Reference samples: EC NRM 171

U-isotope	Areal density	
	NRTA	Reference
^{235}U	$(5.063 \pm 0.090) \times 10^{-4}$ at/b	$(5.0326 \pm 0.0080) \times 10^{-4}$ at/b
^{238}U	$(1.062 \pm 0.010) \times 10^{-2}$ at/b	$(1.0628 \pm 0.0015) \times 10^{-2}$ at/b

NRD: challenges

Develop NRD with a target accuracy for NRTA: 2% on Pu and U content

Challenges (Schillebeeckx et al. 2013):

- Complex transmission spectra due to fission products
- Temperature (Doppler)
- Impact of impurities, i.e. ^{10}B and structural materials
- Inhomogeneity of the samples: diversity in shape and size of the debris samples

Solutions

- Model to account for matrix materials: Include a dummy element X with a cross section:

$$n_X \, \sigma_{tot,X}(E) = a_X + \frac{b_X}{\sqrt{E}}$$

- Model to account for diversity in shape and size of the debris validated by measurements at GELINA (Becker et al., 2014)
- Implement models in the code used for analysis of transmission data, i.e. REFIT code

Perspectives

- After the Fukushima accident, new research programmes have started to extend the experimental basis of data for modeling tools and fill some gaps.

- In JRC, some R&D activities on nuclear safety are refocused to cover specific issues related to the Fukushima accident and to its aftermath, covering fuel and reactor safety, accident modeling, non-destructive characterization methods, spent fuel/debris characterization in view of retrieval and conditioning, etc.

- The ongoing activities benefit from the existing knowledge on severe accidents, accumulated in previous international projects, and from advanced experimental capabilities available today.

- Links/collaboration with Japanese partners and with EU Member States organizations are being developed.

- Integrated approaches are a necessity to optimize use of resources and to exploit complementarity among different organizations
→ international partnerships/programmes
→ integrated experimental/theoretical

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