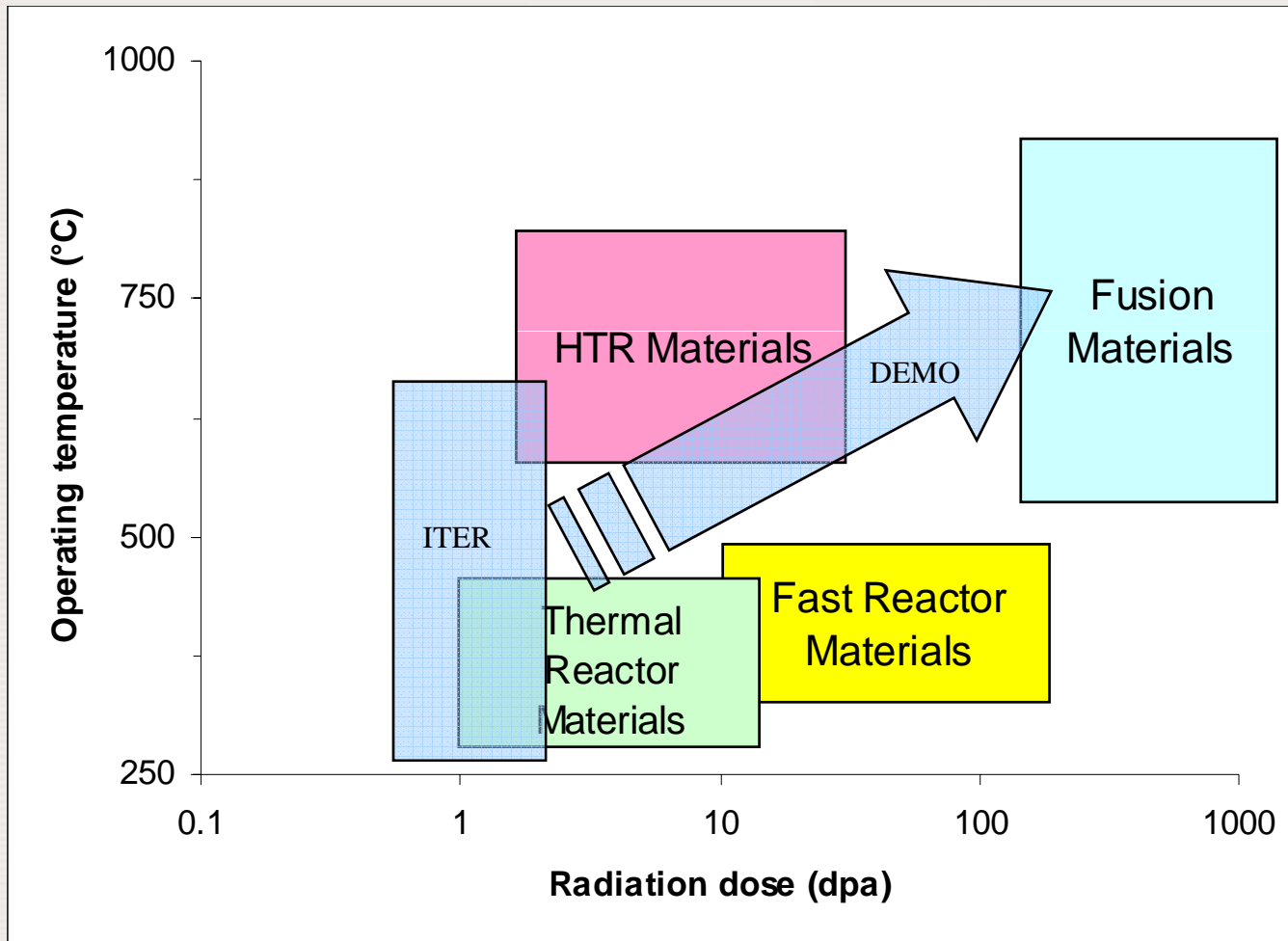


***IAEA activities in the areas of  
fuel performance analysis and  
radiation-resistant materials development***

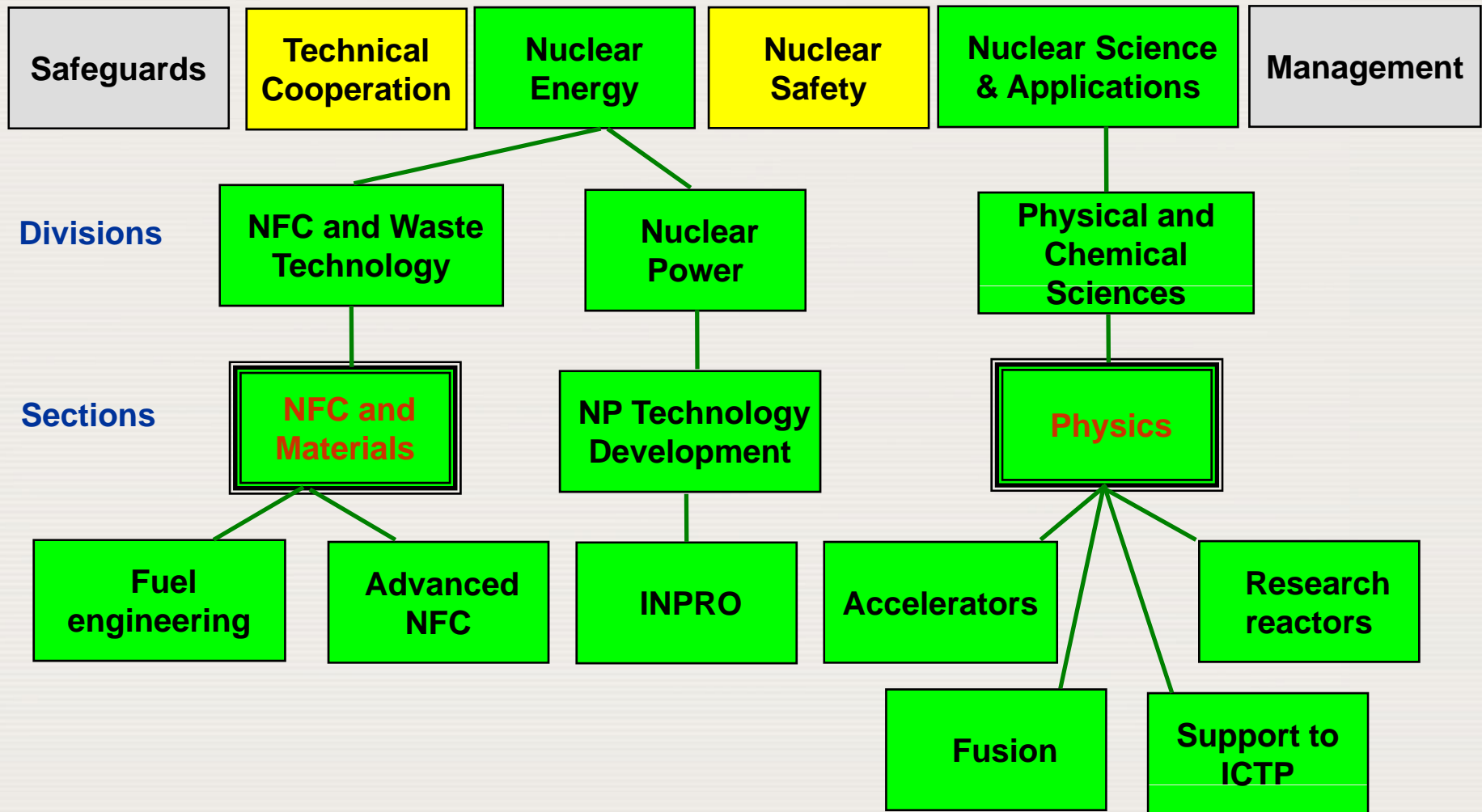
**Victor Inozemtsev  
NE / NEFW / NFCM / Fuel Engineering**



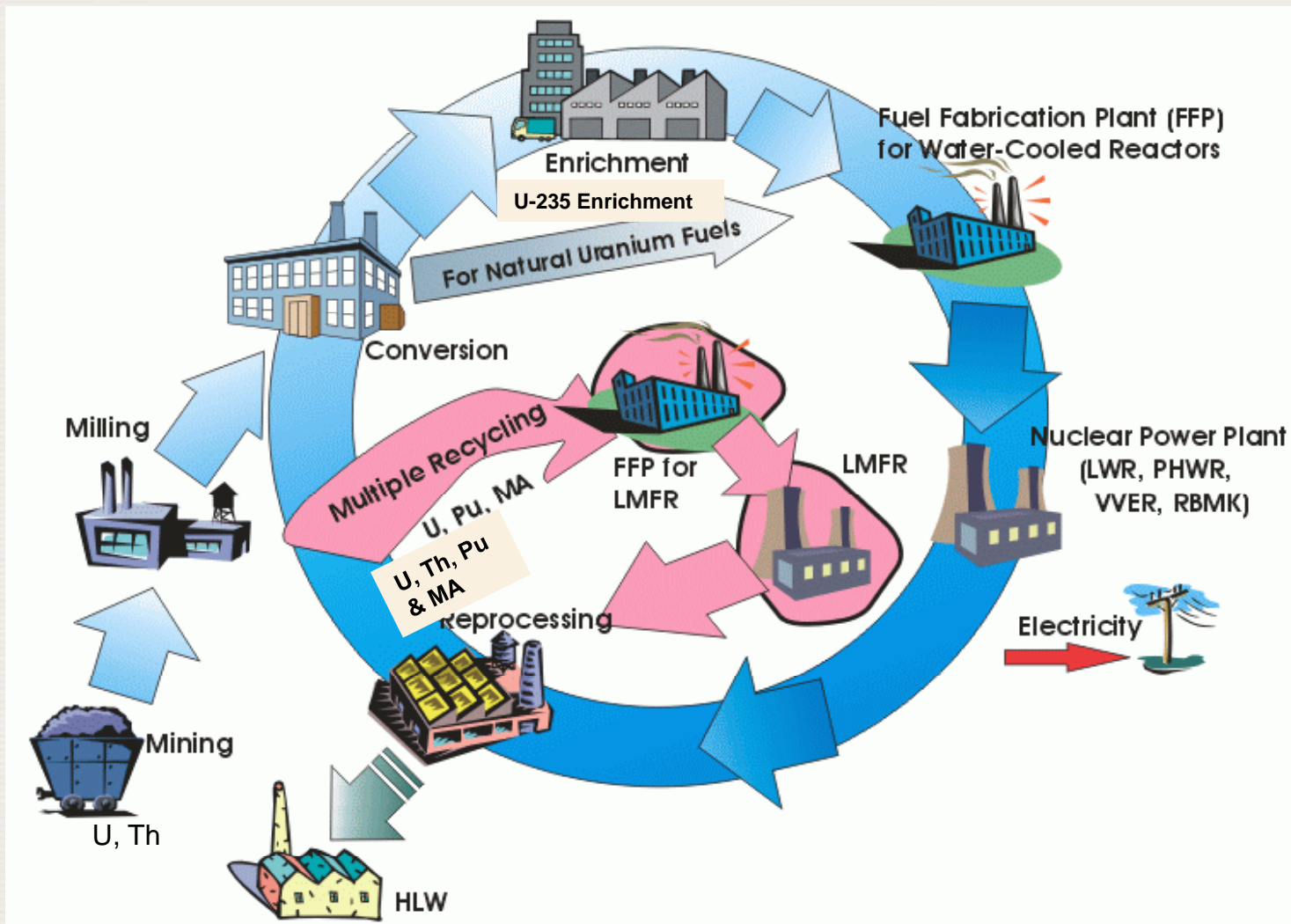
# Increasing demands on structural materials



# Advanced materials in the IAEA Major Programme “Nuclear power, fuel cycle and nuclear science”



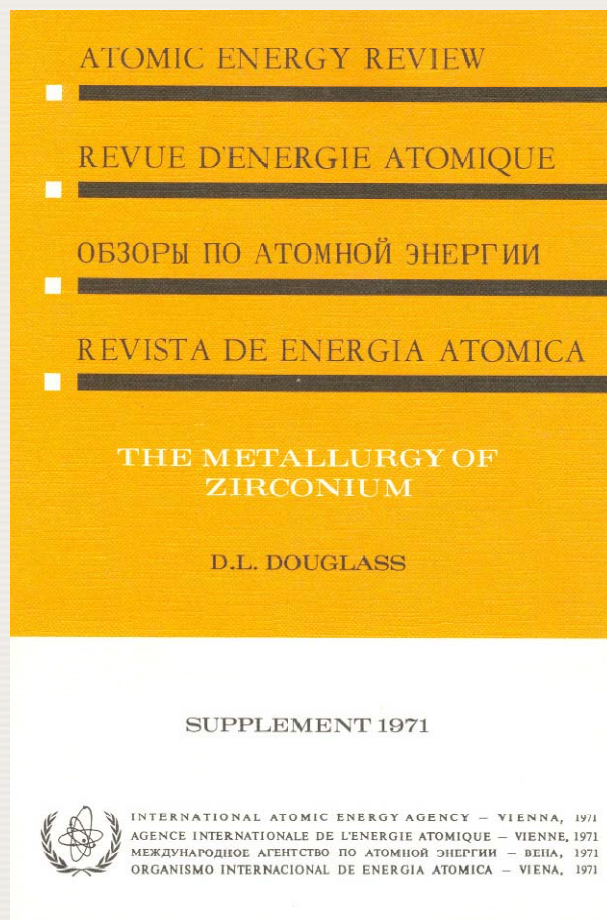
# Nuclear Fuel Cycle and Materials Section



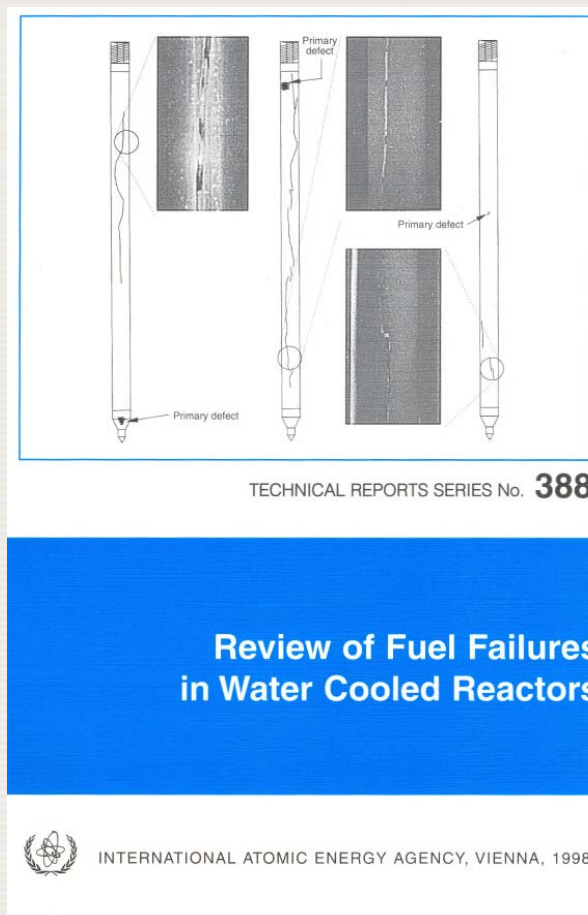
# Technical Meetings (TWGFPT-2008)

Technical Meetings	Host	1	2	3	4	5	6	7	8	9	10	11
TWGFPT	IAEA	■	■	■	■	■	■	■	■	■	■	■
Advanced PIE examination techniques for water reactor fuel - TECDOC-1277	Russia	■										
Fuel behavior under transient and LOCA conditions - TECDOC-1320	Norway	■										
Fuel failure in water reactors: causes and mitigation - TECDOC-1345	Slovakia		■									
Poolside inspection and repair of water reactor fuel - WM-25642	Czech Rep.			■								
Improved fuel pellet materials and designs-TECDOC - 1416	Belgium			■								
Structural behavior of fuel assemblies, TECDOC - 1454	France				■							
Behavior of high corrosion-resistant Zr-based alloys	Argentina					■						
Fuel behavior modeling under normal, transient and accident conditions and high burnup	UK					■						
High burnup fuel experience and economics	Bulgaria						■					
Hot cell PIE and poolside inspection techniques for water reactor fuel	Argentina						■					
PHWR fuel modelling	India						■					
Fuel rod instrumentation and in-pile measurement techniques	Norway							■				
PHWR fuel design, fabrication and performance	Argentina								■			
Advanced fuel pellet materials and fuel rod designs for water cooled reactors	Switzerland								■			
Fuel behavior and modeling under LOCA and RIA conditions	Japan									■		
Water chemistry and clad corrosion/hydridding/deposition including fuel failures	Ukraine										■	
Design, manufacturing and radiation behaviour of FR fuels (joint)	Russia											■
Fuel integrity during normal operation and accident conditions in PHWR	Romania											■
Hot-cell PIE and pool-side inspection (in cooperation with HOTLAB)	Slovakia											■
Fuel modelling	Finland											■

# Expert Reviews



2009: Zr-book



2009: new edition, 1994–2006

# Contents of the IAEA Review of fuel failures in water-cooled reactors (1994-2006, 94% of WRs)

## **1 INTRODUCTION**

## **2 EVOLUTION OF FUEL OPERATING ENVIRONMENT AND DESIGN FUEL CHANGES**

### 2.1 EVOLUTION OF FUEL OPERATING ENVIRONMENT

### 2.2 FUEL DESIGN EVOLUTION

### 2.3 FUEL TYPES IN OPERATION

## **3 WORLD OVERVIEW ON FUEL FAILURES IN 1994-2006**

### 3.1 INTRODUCTION

### 3.2 COOLANT ACTIVITY LEVELS

### 3.3 METHODOLOGY OF FUEL FAILURE RATE EVALUATION

### 3.4 COLLECTION AND TREATMENT OF FUEL FAILURE DATA

### 3.5 EVALUATION OF PWR FUEL LEAKERS

### 3.6 EVALUATION OF BWR FUEL LEAKERS

### 3.7 EVALUATION OF WWER FUEL LEAK RATE

### 3.8 EVALUATION OF FUEL LEAKAGE IN CANDU/PHWR

### 3.9 MULTIPLE FAILURE INCIDENTS/DEFECT EXCURSIONS

### 3.10 FUEL ROD FAILURE RATES AND FUEL FAILURE CAUSES DURING 1987-2006

### 3.11 EVALUATION OF WORLD AVERAGE LWR FUEL FAILURE RATES

### 3.12 CONCLUDING REMARKS ON CHAPTER 3

## **4 DETECTION, EXAMINATION AND ANALYSIS OF FUEL FAILURES**

### 4.1 INTRODUCTION

### 4.2 EVALUATION OF COOLANT ACTIVITY

### 4.3 LOCALIZATION OF FUEL FAILURES

### 4.4 FUEL EXAMINATION

### 4.5 FUEL FAILURE ANALYSIS

## **5. MECHANISMS AND ROOT CAUSES OF FUEL FAILURE**

### 5.1 INTRODUCTION

### 5.2 GRID-TO-ROD FRETTING

### 5.3 FRETTING BY DEBRIS

### 5.4 CORROSION

### 5.5 PCI (PELLET-CLADDING INTERACTION)

### 5.6 MANUFACTURING DEFECTS

### 5.7 CROSS FLOW/BAFFLE JETTING

### 5.8 PRIMARY HYDRIDING

### 5.9 DELAYED HYDRIDE CRACKING (DHC)

## **6 FUEL STRUCTURAL DAMAGE AND OTHER FUEL ASSEMBLY ISSUES**

### 6.1 ASSEMBLY BOW

### 6.2 MECHANICAL DAMAGE DURING HANDLING

### 6.3 CRUD & AXIAL OFFSET ANOMALIES (AOA)

### 6.4 OTHER MISCELLANEOUS DAMAGES

## **7 SECONDARY FUEL FAILURES**

### 7.1 BACKGROUND

### 7.2 OBSERVATIONS FROM EXPERIENCES

### 7.3 DEGRADATION CHARACTERISTICS

### 7.4 MECHANISMS

## **8 FUEL FAILURE PREVENTION AND MANAGEMENT IN PLANT OPERATION**

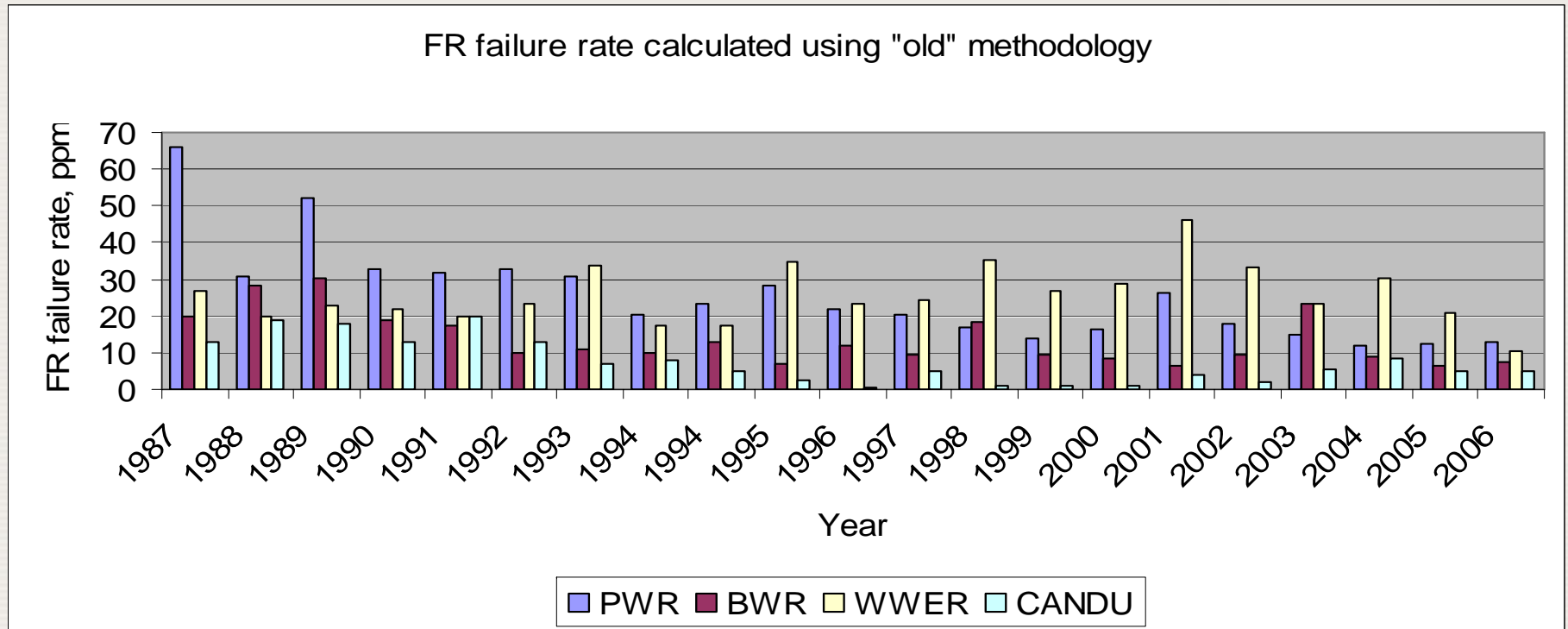
### 8.1 EXISTING OPERATING LIMITS AND RECOMMENDED PRACTICES

### 8.2 IMPROVEMENT OF QUALITY DURING MANUFACTURING

## **9 CONCLUSIONS**



# Evolution of fuel failure rate: 1987 -2006



**The combination of results from the previous and present IAEA Fuel Failure Reviews reveals a tendency for reduction of fuel failure rate, but with recurrent increases linked mainly to massive fuel failures.**



# IAEA Coordinated Research Projects (CRP): Delayed Hydride Cracking (DHC)

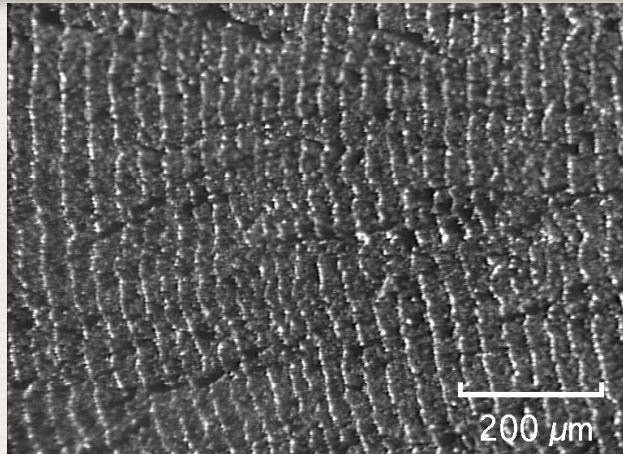
Phase 1: DHC-1 “Delayed Hydride Cracking in Zr alloys in pressure tube nuclear reactors” 1998-2002  
IAEA TECDOC-1410

ORGANIZATION	COUNTRY
AECL	Canada
STUDSVIK	Sweden
CNEA	Argentina
BARC	India
KAERI	R. of Korea
LEI	Lithuania
PINSTECH	Pakistan
INR	Romania
VNIINM	Russia
NPIC	China

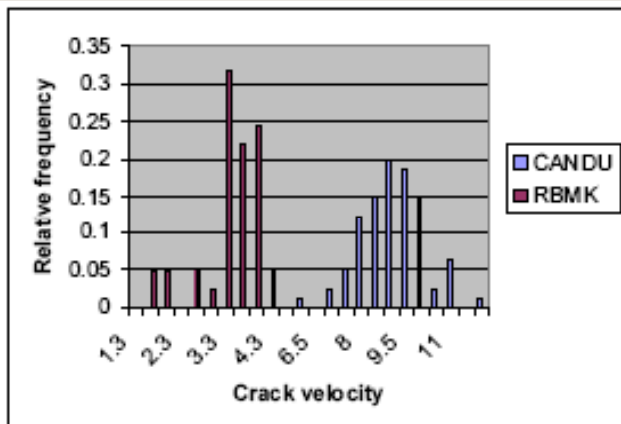
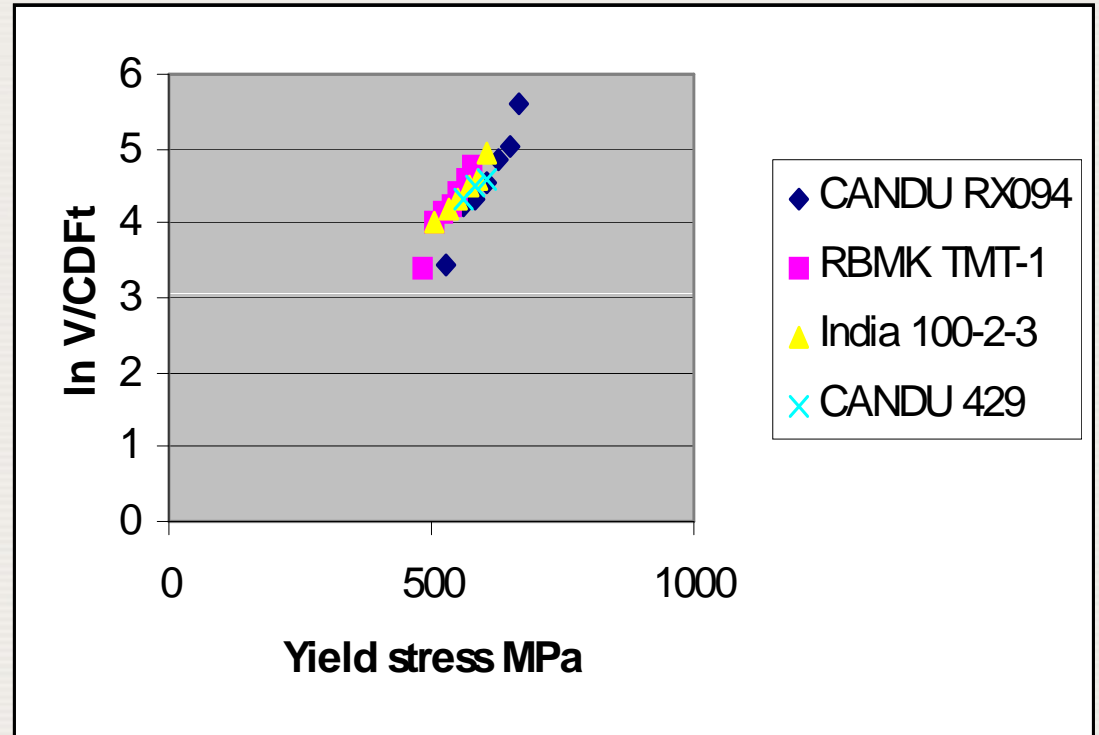
Phase 2: DHC-2 “Delayed Hydride Cracking of Zr alloys fuel cladding” 2005 - 2009  
(TECDOC under preparation)

ORGANIZATION	COUNTRY
STUDSVIK	Sweden
TOMARI Consulting	Canada
CNEA	Argentina
BARC	India
KAERI	R. of Korea
LEI	Lithuania
PINSTECH	Pakistan
INR	Romania
VNIINM	Russia
IPEN	Brazil

# DHC: Zr-2.5% Crack Velocity Results



DHC striations, CANDU, 283°C



CANDU and RBMK, 250°C (m/s x 10<sup>-8</sup>)

# IAEA Coordinated Research Projects (CRP): Fuel Behaviour Modelling Program

- DCOM (1981-1985). Development of Computer Models for fuel element behaviour in water reactors. 15 participants from 12 countries. *Need to improve temperature and FGR predictions.*
- **FUMEX-1** (1993-1996). Fuel modelling at extended burnup. 19 participants from 14 countries. International Fuel Performance Experimental database (IFPE). *Need to improve mechanical interaction and extend burnup for FGR.*
- **FUMEX-2** (2001-2006). 18 participants from 16 countries. *Uncertainty on high burnup effects, rim structure and PCMI.*
- **FUMEX-3** (2008-2011). About 30 participants from 20 countries. The exercise is designed to consider transient behaviour, mechanical interaction and other high burnup behaviours.

# Joint OECD/NEA–IAEA International Fuel Performance Experiment (IFPE) Database:

The public IFPE Database on for the purpose of fuel behaviour **code development and validation** is located at:

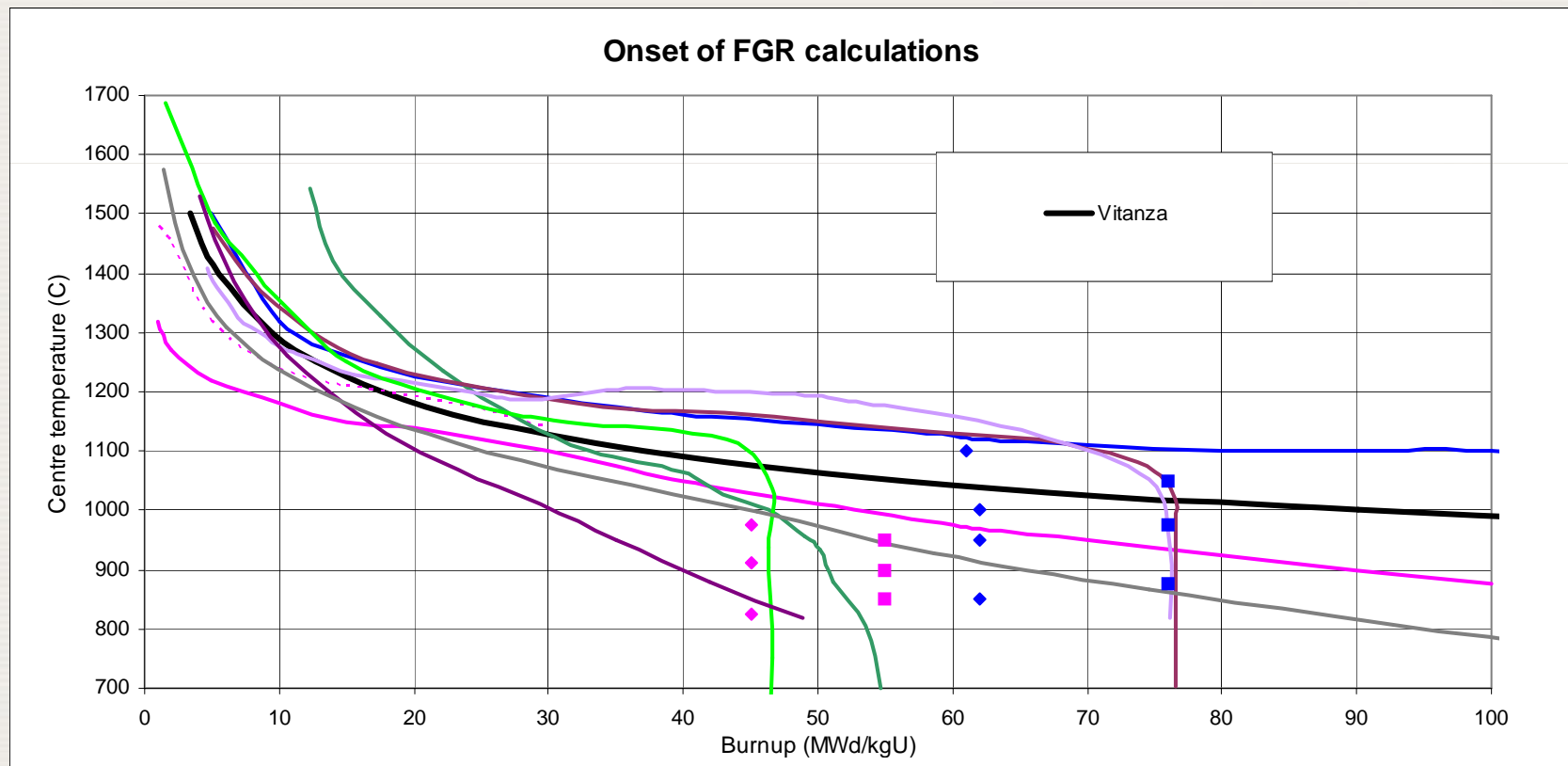
<http://www.nea.fr/ntml/science/fuel/ifpelst.html>

Well-qualified data on **Zr - UO<sub>2</sub>** fuel that illustrate specific aspects of fuel performance.

In addition to direct **in-pile** measurements, the database includes **PIE** information on clad diameters, oxide thickness, hydrogen content, fuel grain size, porosity, Electron Probe Micro Analysis (EPMA) and X-ray Fluorescence (XRF) measurements on caesium, xenon, other fission product and actinides.

# Predictions of the Vitanza threshold (CRP FUMEX)

The codes were asked to predict the temperature at which 1% fission gas release occurs as a function of burnup. The Vitanza threshold is experimentally derived, but **only to a burnup of around 40GWd/tU**



# CRP on Accelerator Simulation and Theoretical Modeling of Radiation Effects (SMoRE)

## WHY

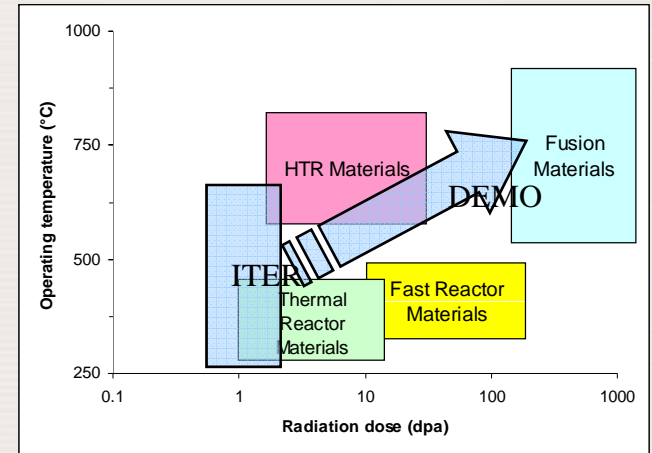
- Growing operational requirements and their variability
- Growing cost and duration of direct irradiation tests
- Not sufficient understanding of radiation effects

## WHAT

- Both existing and perspective structural materials
- Both practical tasks and basic research

## WHEN

- 2007 – Round Table at the AccApp'07, Consultancy in the IAEA
- 2008 – Technical Meeting in KIPT  
1st Research Coordination Meeting in Vienna
- 2009 – Contracts and Agreements: Belgium (SCK.CEN), China (CIAE), France (CEA, EdF), India (BARC), Poland (IAE), Russia (IPPE, KI), Slovakia (BU), Spain (IFN), Ukraine (KIPT), USA (LLNL), OECD (NEA), RoK (KAERI)




# Workshops and Conferences (NE+NA)

## 2009

International Topical Meeting on  
**Nuclear Research Applications  
 and Utilization of Accelerators**

4-8 May 2009  
 Vienna, Austria



IAEA  
 International Atomic Energy Agency  
 Atoms for Peace

American Nuclear Society

www.iaea.org/meetings  
 CR-173

**ICTP** The Abdus Salam  
 International Centre for Theoretical Physics

**WORKSHOP on  
 BASIC RADIATION MATERIALS  
 SCIENCE**

10 - 21 November 2008  
 Miramare, Trieste, Italy

The Abdus Salam International Centre for Theoretical Physics (ICTP, Trieste, Italy), in cooperation with the International Atomic Energy Agency (IAEA, Vienna, Austria), is organizing a Workshop on the Training in Basic Radiation Materials Science and its Applications to Radiation Effects Studies and Development of Advanced Radiation-Resistant Materials, to take place in Trieste from 10 to 21 November 2008.

**Background:**  
 Growing requirements on nuclear fuel performance parameters (e.g. higher burnup, residence time, reaction temperature) increasingly demand the introduction of technical innovations and advanced materials. The testing of such materials by direct irradiation carries an increase in cost and duration of these studies. Within this context, it is clear that the development of theoretical models of radiation effects and nuclear fuel behavior requires a prominent role. Radiation materials science provides the basic understanding of the nature of radiation damage, and allows for an adequate comparison and interpretation of simulation experiments against data collected in accelerators and other irradiation devices.

**Content Description:**  
 The Workshop is intended to provide participants with basic information about present and future requirements on nuclear materials, modeling and simulation of radiation effects, advanced experimental tools and modern approaches for development of radiation-resistant materials. Specific topics include:

- Operational conditions and requirements for nuclear materials
- Physics of radiation damage and radiation effects
- Modern post-irradiation examination techniques and methods
- Modeling of radiation effects and nuclear fuel behavior under irradiation
- Applications of accelerators for modeling of radiation damage
- Development of materials subject to high dose irradiation

Participants are encouraged to present their work in a Poster session to be held during the first week of the Workshop. A few posters will be selected, and their authors will be offered the opportunity to give a brief oral presentation.

**Participants:**  
 The invitation to the Training Workshop is directed to scientists and engineers in academia, industry and possibly in the governmental sector who are involved in research in the general area of radiation damage of materials subject to very high dose radiation, e.g. materials used in nuclear reactors.

Applicants from all countries who are members of the UN, UNESCO or IAEA may apply. As the Workshop will be held in English, participants must have a good working knowledge of that language. Although the main purpose of the Centre is to help research workers from developing countries through a programme of training activities within a framework of international co-operation, a limited number of students and post-doctoral scientists from developed countries are also welcome to attend.

As a rule, travel and subsistence expenses of the participants should be borne by the home institutions. However, limited funds are available for some participants who are nationals of, and working in, a developing country and who are not more than 42 years old, to be selected by the Organizers. As security of funds allows travel to be granted only in a few exceptional cases, every effort should be made by candidates to secure support for their fare (or at least half fare) from their home country. It is stressed that participants whose travel expenses are paid by ICTP are required to attend the entire activity. For logistics reasons, the total number of participants is limited. There is no registration fee for this activity.

The Application Form is obtainable from the ICTP WWW server: [http://cds.cern.ch/record/119111/files/iaea\\_iaea\\_08\\_07\\_2008.pdf](http://cds.cern.ch/record/119111/files/iaea_iaea_08_07_2008.pdf) (which will be progressively up-dated, or from the activity document). It should be completed and returned before **10 JULY 2008** to:  
**Workshop on Basic Radiation Materials Science (year 1909)**  
 the Abdus Salam International Centre for Theoretical Physics  
 c/o Elizabeth Francovich  
 Strada Costiera 11, I-34014 Trieste, Italy

The decision of the Organizers will be communicated to all candidates as soon as possible.

**If sending your applications by e-mail:** [iaea1909@ictp.it](mailto:iaea1909@ictp.it)  
 (Please save and send the attachments in PDF format)

Telephone: +39 040 2241284      Telefax: +39 040 2241643  
 E-mail: [iaea1909@ictp.it](mailto:iaea1909@ictp.it)      ICTP Home Page: <http://www.ictp.it/>

Trieste, April 2008

in cooperation with  
 International Atomic Energy Agency  
 Vienna

**DIRECTORS**  
 V. INOZEMTSEY  
 (IAEA, Vienna)  
 J. KOJANOFF  
 (Queen's University, Belfast)

**LOCAL ORGANIZER**  
 S. Scandola  
 (ICTP, Trieste)

**DEADLINE**  
 for requesting participation  
**10 July 2008**

## 2008, 2009, (2010)



***You are welcome!***