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Introduction of Two New IAEA Collaborative Research Projects – Benchmarking Multi-Unit PSA Models and Prediction of Piping System Failure Rates in Advanced Water-Cooled Reactor

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Overview of Presentation

- Background and Motivation

- General Approach for MUPSA
- Data Base on Pipe Failures
- Planned CRP Framework and Schedules
- Summary

Background

NPP site may typically have several reactor units, often of different designs, and up to 10!

Current practice:

"Risk" is calculated using single-unit Probabilistic Safety Assessments (PSA)

The 4-Unit VVER-440 Dukovany NPP (Source: Wikipedia)

What is the risk (to the Public) from a large NPP site?

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Does it matter how a severe accident is initiated (internal/external)?

How many cores melt?

How many sources or releases?

Which source?

What are the additional *MU site* considerations?

- Common Location
- Common Facilities
- Shared Equipment
- Consequential Events
- Staffing and “Mutual Aid”

How often will a severe accident occur?

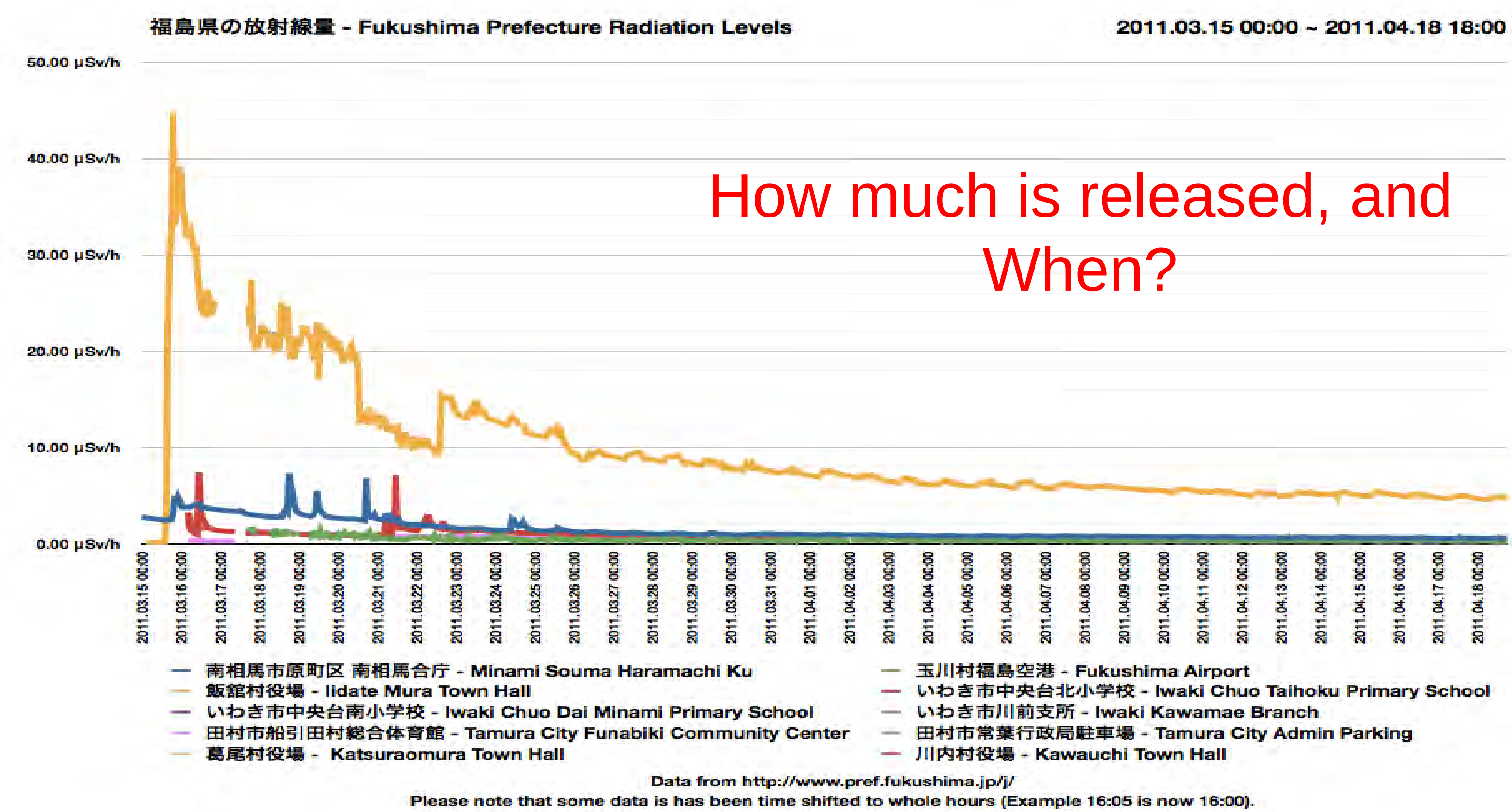
How can the risk (to the Public) be quantified?

How many cores melt?

How many sources or releases?

Which source and when? TIMING!

→ Release (source term) and plume dispersion



How much is released, and When?

What is the IAEA doing/planning?

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Nuclear Safety Dep’t has undertaken activities to include MU considerations into their Safety Guides, post-Fukushima. Nuclear Energy Dep’t is putting this into practice:

Two new CRP’s are launched in early 2018:

1. **PSA Benchmark on Multi-Unit/Multi-Reactor Sites**
2. **Using existing Pipe Failure Rates to Predict Advanced WCRs *(PSA input parameter)***

What is the IAEA-NENP planning?

…so let’s put it into practice and gain some knowledge, by doing benchmark/pilot studies...

Two new CRP’s are launched in early 2018:

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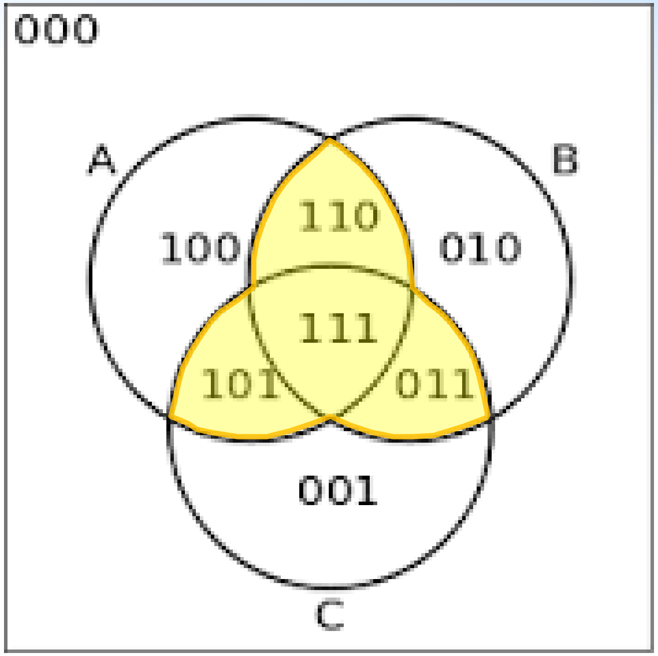
1. MUPSA CRP Framework/Scope

- **<u>PSA focus within this CRP:</u>**
  - Risk from multi-unit accidents (not single-unit risks)
    - ✓ *The yellow part of the Venn diagram*
  - Level-1 and Level-2 (limited to LRF)
  - At-power operation of all NPP units
  - Reactor cores and SFPs
  - ➢ *The suggested **restriction of the PSA scope** is due to the need to **limit resources** to develop PSA models and perform the analysis*



Venn diagram illustrating the scope of MUPSA for a 3-units case

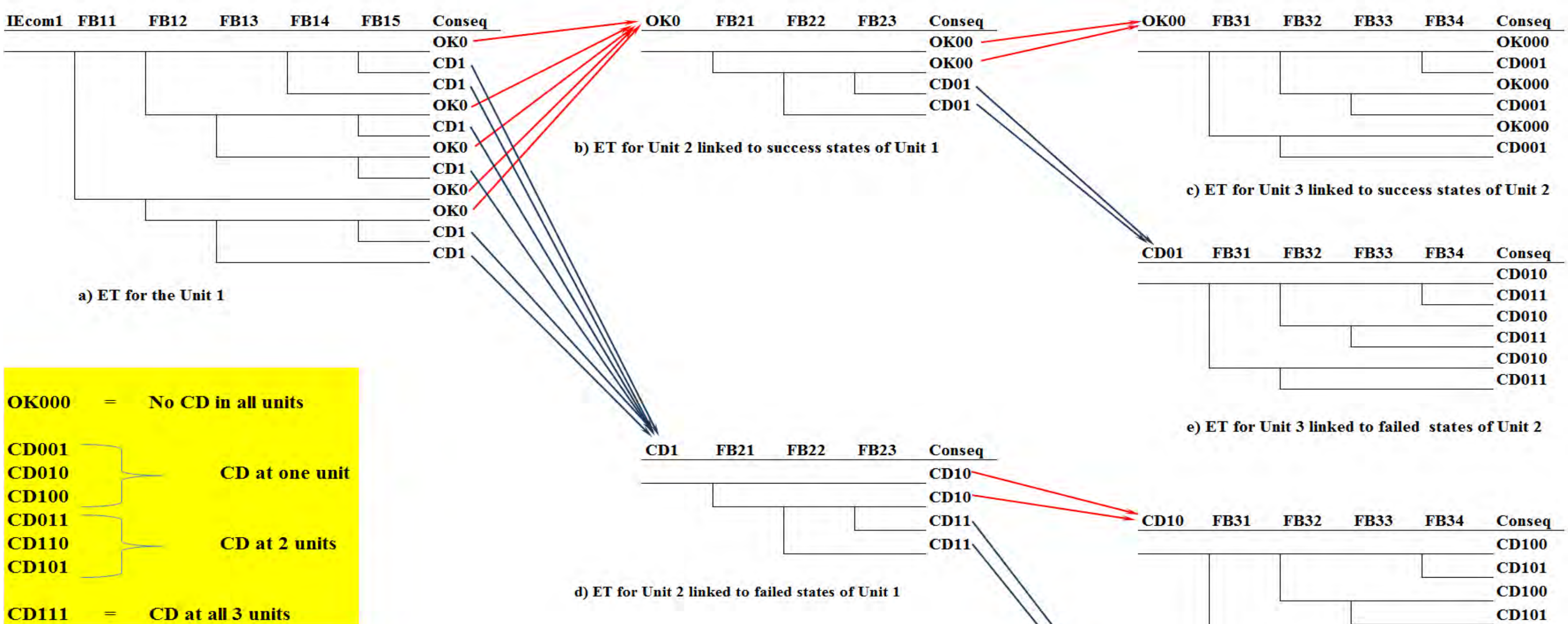
- ➢ ***…BUT, Flexibility** will be exercised as appropriate (at 1st Research Coordination Meeting) based on the feedback from the participants*
  - ✓ Possible extension of the PSA scope in terms of operational modes, other sources of radioactivity on the site, single-unit risk, etc., if deemed necessary

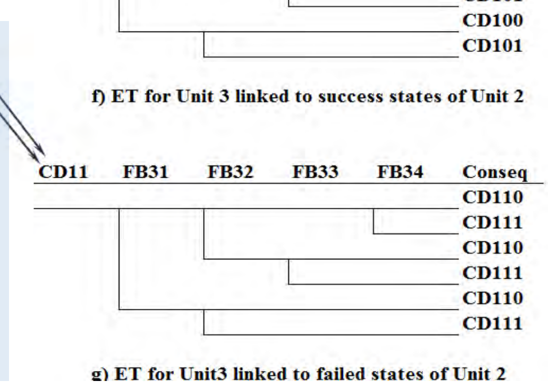
1. General Approach for Level-1 MUPSA (1/2)

- A general approach for MUPSA was developed based on TECDOC-1804, taking into account other available material
- The main idea of the general approach is ***to consider the multi-unit site as one 'integral facility'*** with several reactor cores and spent fuel pools
  - The extent of damage of this **'integral facility'** can vary, so that ***several potential damage states*** can be identified for the facility
- The challenge is to construct a PSA model that allows to quantify the frequency of core/fuel damage on one, two or other combinations of plant units/SFPs at the site
  - This can be achieved by constructing a single multi-unit ET (linking single unit ETs) that would allow distinguishing different end states
  - This is in line with the attribute AS-B01-S1 of TECDOC-1804
- Ten general steps of a Level-1 MUPSA have been outlined

1. General Approach for Level-1 MUPSA (2/2)

A Novel Approach of Linking Single-Unit ETs (related to Step 3 of General Procedure)





Note 1: Available single-unit ET models are largely used

Note 2: Overall small ET/large FT modeling approach is more appropriate for MUPSA

Note 3: Single unit ETs become 'transfer' ETs with relevant end states (the structure is kept)

Note 4: The number *m* of new 'transfer' ETs to be included in the model for *n* units:

$m = 2^n - 2$ e.g. for n=3, m=6; for n=4, m=14; for n=8, m=62

Note 5: In the same manner ET for reactor and SFP can be linked

→ ***More details in Annex 2 of Consultancy Meeting Report***

What is the IAEA-NENP planning?

…so let's put it into practice and gain some knowledge, by doing benchmark/pilot studies...

Two new CRP's are launched in early 2018:

1. **PSA Benchmark on Multi-Unit/Multi-Reactor Sites**
2. **Using existing Pipe Failure Rates to Predict Advanced WCRs *(PSA input parameter)***

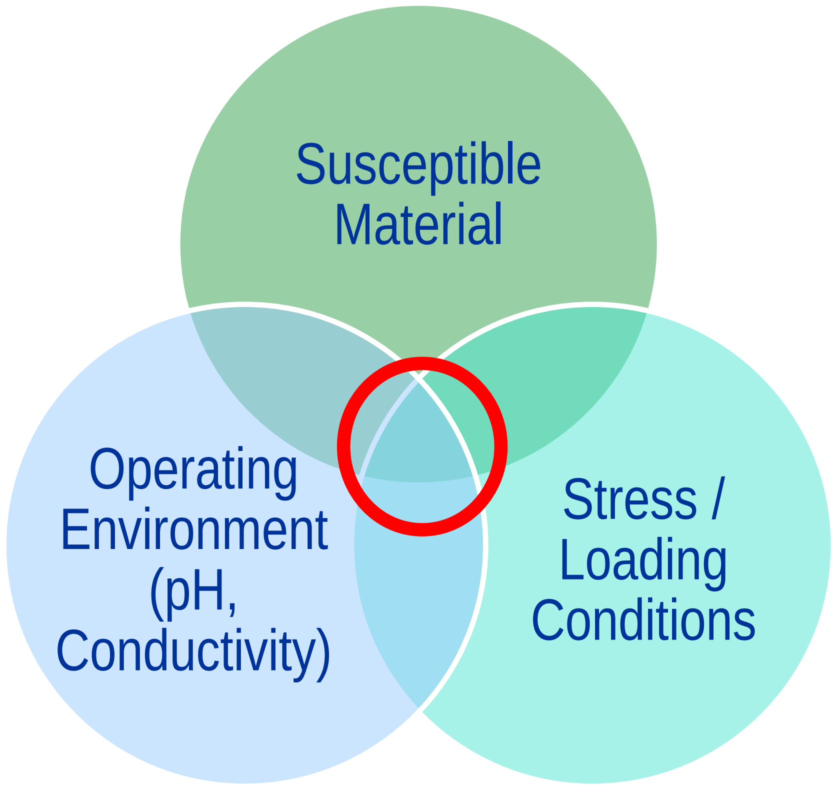
2. Piping Reliability or Failure Frequency

Why Perform Piping Reliability Analysis?

Qualitative and quantitative piping reliability considerations enter into:

- Formulation of pre-service & in-service inspection programs
- Plant-specific probabilistic safety analysis (PSA)
  - Loss-of-coolant-accident (LOCA) initiating event frequency
  - LOCA spatial effects assessments
  - Internal flooding PSA
  - High-energy line break (HELB) analysis
- Design certification of advanced WCRs, including design certification PSA
- Operability determination of degraded/failed piping, including fitness-for-service assessments

Conjoint Requirements for Pipe Degradation & Failure



2. Why this Topic?

- Advanced WCR Piping Designs envisaged to adopt
  - Advanced materials
  - Novel fabrication processes
  - Advanced leak detection technology
  - Advanced NDE technologies and qualification processes
  - Novel approaches to in-service inspection, i.e. reliability and integrity management (**RIM**) processes

- Therefore,
  - **In the absence of OE-data**, a strong need for piping reliability estimates that build on the collective knowledgebase and adjusted (in a probabilistic sense) to reflect the unique advanced WCR piping designs

2. CRP Objectives & Goals

- Contribute to MUPSA CRP
- Develop 2 benchmarks
- Develop new workshops
- Develop new training and education courses
- Publish NES and TecDocs
- Publish papers

- **Provide Member States with methods & techniques to derive pipe failure rates for advanced WCRs**
  - Probabilistically, apply an informed technical approach (e.g. PFM) to apply 'adjustment factors' to pipe failure rates derived on the basis of the very extensive operating experience from operating reactors
  - Address advanced materials and the potential ageing effects using a structured process, e.g. SRMs
  - Express uncertainties in a comprehensive & defensible way

2. CRP Activities and Schedule

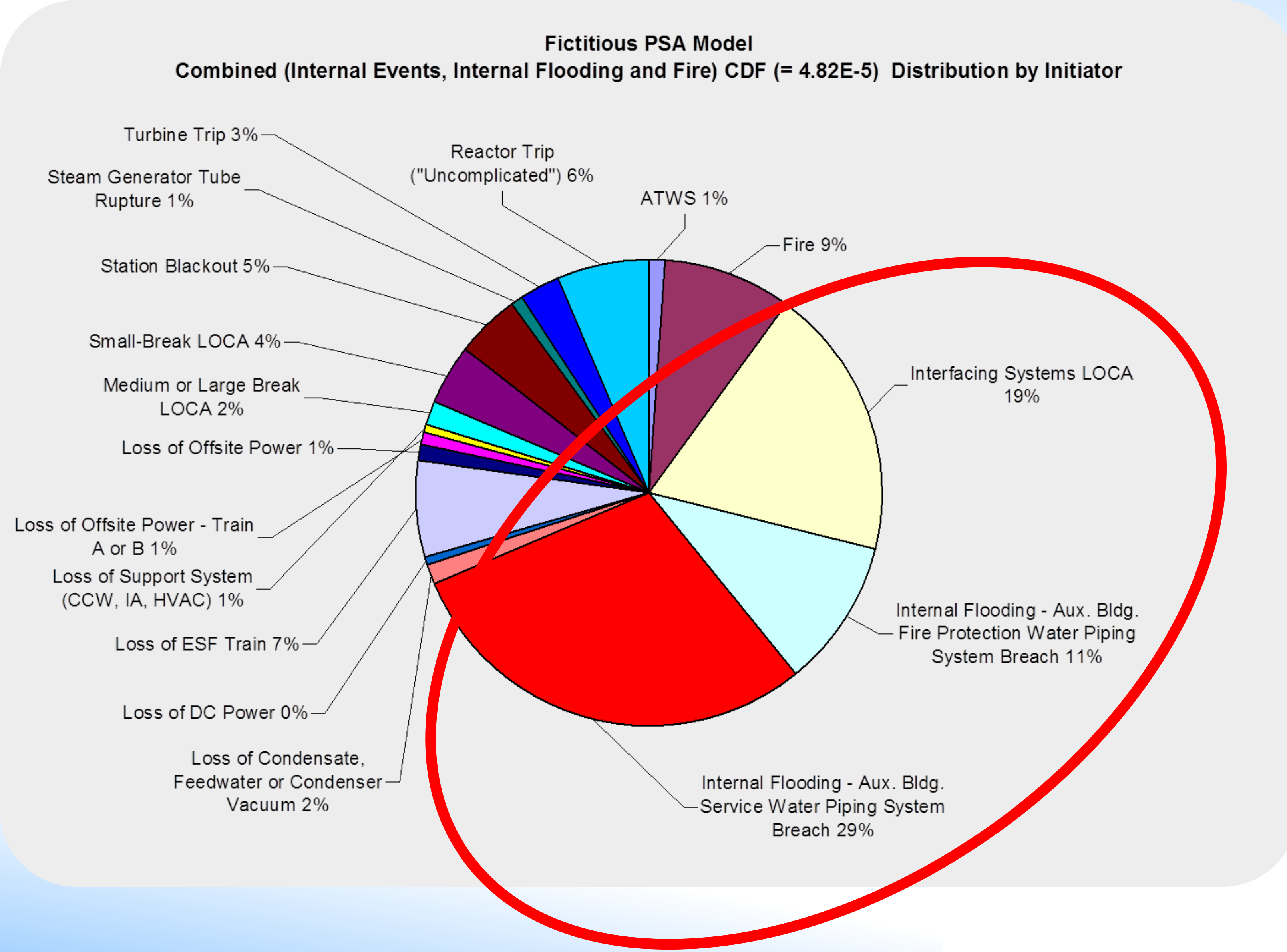
Stylized problems to be solved by selected & well qualified analysis teams from at least five Member State organizations (TSOs, Academia, National Labs., Industry)

- Two benchmark exercises, from advanced WCR system or systems, could be for a specific component type/location
- Contrast-and-compare
- Summarize insights and develop commendable practices
- Technical work to be performed during **2018 through end of 2020**
- **1st RCM: Early 2018**

Benchmarks

- Benchmark No. 1. & 2
  - Each participating organization to perform analyses in accordance the Work Package Specifications. Interim results and progress reports to be submitted to the CRP Management Team according to schedule.
- 1st Research Coordination Meeting.
  - Problem definition, discussion of technical approaches, including an overview the piping reliability analysis state-of-the-art, insights from past projects to derive pipe failure rates for advanced WCRs.
  - A highly detailed format for discussions will be provided to each participation organization prior to the RCM.
  - The outcome of the 1st RCM shall be in the form of detailed specifications for the first benchmark, which focuses on the technical approach to the derivation a priori failure rates distributions for a well-defined set of piping systems, materials and operating environments.

The Connection: Contribution to PSA Risk from Pipe Failures



Summary – “MUPSA”

- The new CRP on *PSA Benchmark on Multi-Unit/Multi-Reactor Sites* proposes:
  - ✓ Synergistic integration with related IAEA activities
  - ✓ A general approach for MUPSA that is based on the recent IAEA TECDOC-1804 and SSG-3
- The overall objective of CRP is to foster collaboration among MSs and learn from each other through performing practical MUPSA analyses and sharing experience/insights
  - ✓ No prescribed methods, only general approach for MUPSA outlined
- The overall scope to be covered within CRP includes (limited) Level-1 (CDF) and Level-2 (LRF) PSA

Interested Participants should submit their Specific Proposal on IAEA CRA website (https//cra.iaea.org/cra)

Summary – "Piping Reliability"

- The new CRP on *Methodology for Developing Pipe Failure Rates for Advanced Water Cooled Reactors* proposes:
  - ✓ Synergistic integration with related IAEA, ASME and EPRI activities
  - ✓ Two stylized benchmark problems to be solved by selected & well qualified analysis teams
- The overall objective of CRP is to foster collaboration among MSs and learn from each other through performing practical analyses and sharing experience/insights
  - ✓ No prescribed methods, deterministic or probabilistic or combination
- The overall scope to be covered within CRP includes two benchmarks to be defined during the first RCM

Interested Participants should submit their Specific Proposal on IAEA CRA website (https//cra.iaea.org/cra)

Thank you!

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https://www.iaea.org/NuclearPower/Technology/CRP/

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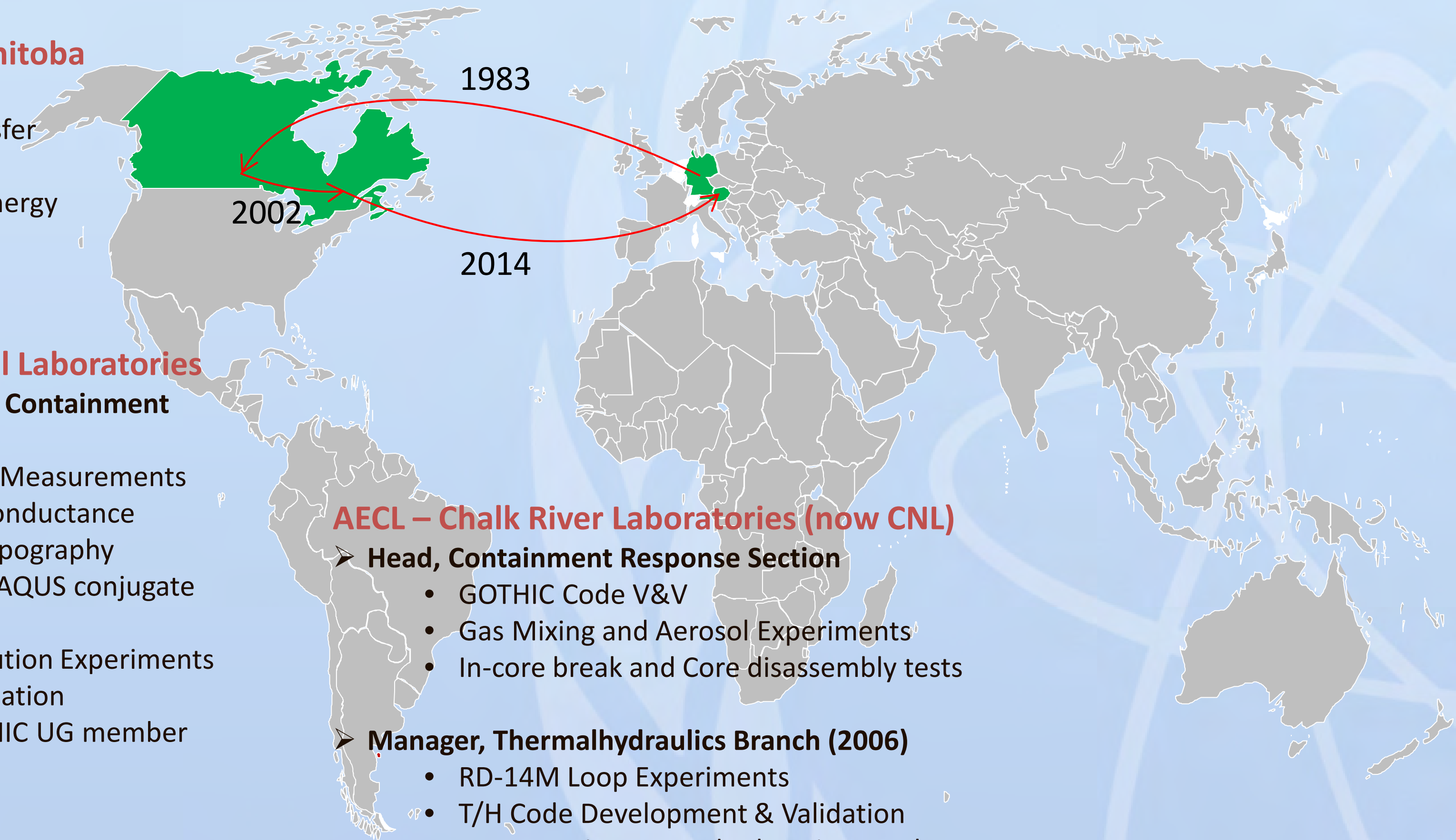
IAEA WCR Team Member for Heavy Water Cooled Reactor Technology Development



University of Manitoba

- B.Sc.(M.E.) 1989
  - Heat Transfer
  - Fluid Flow
  - Nuclear Energy
  - CFD

AECL – Whiteshell Laboratories

- **Fuel Channel and Containment R&D (1989-2003)**
  - Emissivity Measurements
  - Contact Conductance
  - Surface Topography
  - ANSYS/ABAQUS conjugate HT FEM
  - H_2 Distribution Experiments
  - Code Validation
  - EPRI GOTHIC UG member

AECL – Chalk River Laboratories (now CNL)

- **Head, Containment Response Section**
  - GOTHIC Code V&V
  - Gas Mixing and Aerosol Experiments
  - In-core break and Core disassembly tests
- **Manager, Thermalhydraulics Branch (2006)**
  - RD-14M Loop Experiments
  - T/H Code Development & Validation
  - CHF Experiments and others in TH Lab
  - NRU Support

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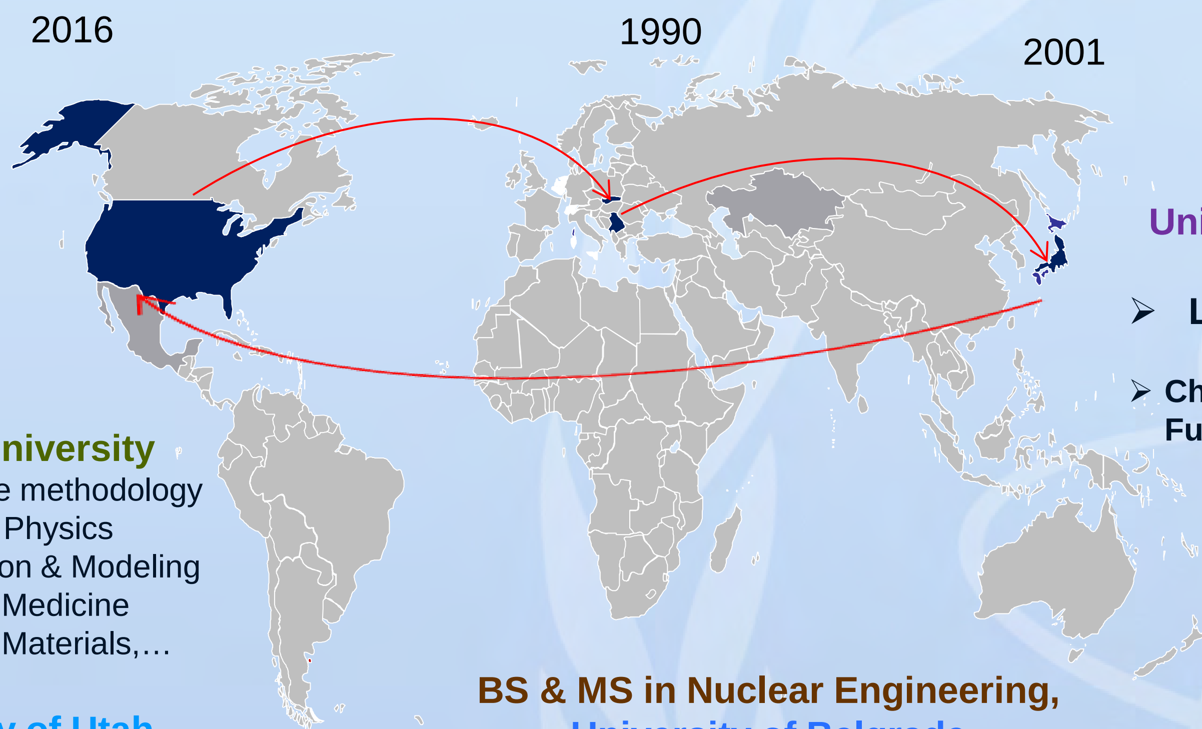
Tatjana Jevremovic

IAEA WCR Team Leader for Water Cooled Reactor Technology Development



PhD in Nuclear Engineering, The University of Tokyo (UT)

- **Lecturer at the UT:**
  - SCWCRs
- **Chief Engineer in Nuclear Fuel Industries:**
  - ANEMONA licensing code
  - Company award

Purdue University

- AGENT code methodology
  - Reactor Physics
  - Simulation & Modeling
  - Nuclear Medicine
  - Nuclear Materials,…

University of Utah

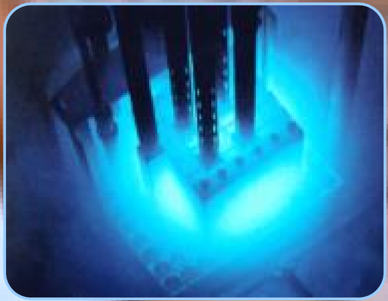
- **Endowed Chair Professor**
- **Nuclear Engineering Program Chair**
- **Director of Nuclear Reactor (TRIGA) and Associated Labs**
  - Nuclear methods, simulation and modeling, nuclear forensics, nuclear materials,…

BS & MS in Nuclear Engineering, University of Belgrade

PM in Energoprojekt Ltd:

- NPP site selection
- Evaluation studies [environmental systems in TPP, NPP, industrial facilities]

IAEA Departments



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Department of Nuclear Energy

- Fosters sustainable nuclear energy development by supporting existing and new nuclear programmes around the world
- Provides technical support on the nuclear fuel cycle and the life cycle of nuclear facilities, and builds indigenous capability in energy planning, analysis, and nuclear information and knowledge management

Promotes the efficient and safe use of nuclear power by supporting existing and new nuclear programmes and facilitating improvements in many areas, including:

- **Performance of nuclear power plants,**
- **Nuclear fuel cycle,**
- **Management of nuclear wastes**
- **Innovation in nuclear power and fuel cycle technologies**
- **Development of indigenous capabilities for national energy planning**
- **Preservation and dissemination of nuclear information and knowledge**
- **Advancement of science and industry through improved operation of research reactors**
- **Education and training**

General Approach for Level-1 MUPSA (2/3)

Step 1	Identification of hazards having potential to impact more than one unit on the site
Step 2	Identification of initiating events having potential to impact more than one unit on the site
Step 3	Modelling of accident sequences involving reactor core/fuel damage for more than one unit (a novel approach is suggested – next slide)
Step 4	Performing fault tree analysis and data analysis as needed by the multi-unit sequence analysis, considering common systems/facilities
Step 5	Modelling inter-units equipment CCF (in addition to intra-unit)
Step 6	Calculating fragilities corresponding to different external hazards and combined events simultaneously or consequentially impacting more than one unit
Step 7	Modelling impact of core/fuel damage at one unit on other units, e.g radiological conditions impact on human reliability
Step 8	Quantification of Level-1 MUPSA model, using site risk metrics
Step 9	Performing sensitivity and uncertainty analyses
Step 10	Producing results and insight from Level-1 MUPSA