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International Nuclear Services

Description of Fuel Integrity Project Methodology Principles

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Looking to the future PATRAM 2010

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Contents

Background: Regulations

- **Issue of package safety:**
  - **In the absence of "multiple high standard water barriers," IAEA regulations (1996 Edition) require that water ingress in the cask cavity in accident conditions of transport (ACT) be considered.**

    → To insure package sub-criticality, it is necessary to have a good understanding of the geometry of the content (LWR fuel assemblies).

  - **In the late 1990s, recurring questions were asked by French and British Competent Authorities (CA) related to fresh and used FA behaviour in transport conditions.**

» **In the early 2000s, TN International (TNI) and International Nuclear Services (INS) started a joint programme, the Fuel Integrity Project (FIP), to better assess LWR FA mechanical behaviour in ACT and to confirm hypotheses for safety-criticality studies.**

FIP History (1/2)

Synthesis of pre-existing data:

- **1980-1990s: Drop tests of FS 69 and FS 74 casks, loaded with dummy PWR and BWR fresh fuel (depleted UO2) assemblies, bending tests on dummy PWR fresh fuel (depleted UO2) pins**

PWR 17x17 fresh fuel assembly loaded in the FS 69 cask

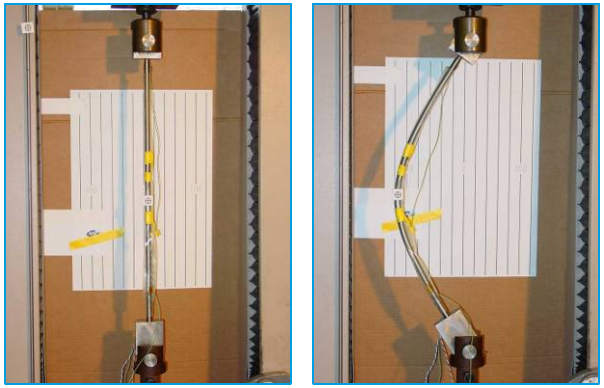
BWR 8x8 fresh fuel assembly loaded in the FS 74 cask

1987 bending test on PWR fresh fuel pins

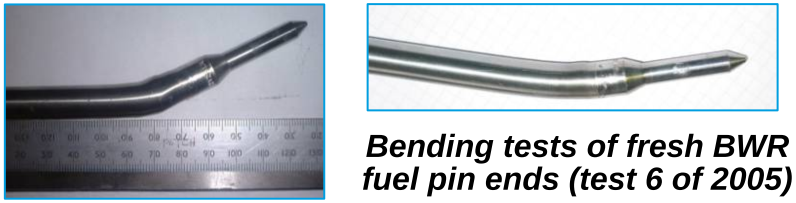
- **Observed phenomena: fuel pin deformation modes, grid and nozzle yielding, fuel pin array deformation and sliding, maximum allowable loads for un-irradiated claddings (bending, axial and transversal compression, shearing, etc.)**
- **Lack of information related to irradiation effects on fuel pins and uncertainties on some loading configurations → Additional tests on fuel pins were carried out**

FIP History (2/2)

- **Complementary mechanical tests:**
  - **2001-2005: 12 tests on <u>fresh</u> (tests 1 to 7) or <u>used</u> (tests 8 to 12) fuel pins and samples**



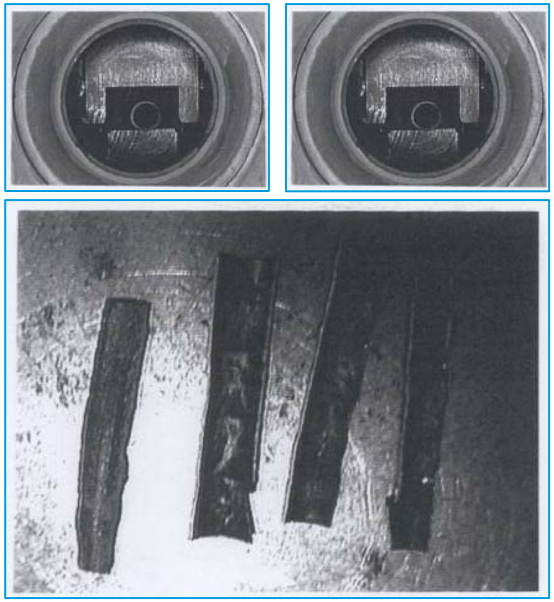
Buckling tests of fresh LWR fuel pin samples (tests 1 to 3)

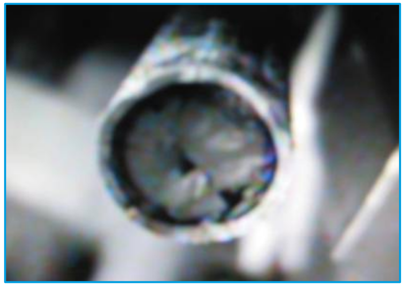


Bending tests of fresh BWR fuel pin ends (test 6 of 2005)

<u>Tests on fresh fuel</u>: samples of pins with Zircaloy claddings and natural or depleted UO2 (in general)

Crushing tests of empty used BWR fuel pin claddings (test 8)





Bending tests of used LWR fuel pin samples (tests 11 to 12)

<u>Tests on used fuel</u>: irradiated samples up to 40-50 GW.d/tU

Building FIP Methodology (1/3)

- **Lessons learned from tests:**

  - → **Main damage to fuel pins and FAs were studied**
  - → **Maximum allowable loads were determined (by result analyses or FEAs)**
  - → **Fresh and used fuel pins were submitted to the same loadings with same boundary conditions → Same maximum loading sites, same rupture sites but only deformation extent was modified by irradiation effects**

» Methodology structure based on FA damage analysis

Building FIP Methodology (2/3)

Methodology main principles:

- Loading and deformation modes of fuel pins and potential rupture sites are specific to the drop direction.
- Analytical models are generally based on similarity calculations with a reference test. In the cladding elastic domain, direct calculations are possible.
- Similar analytical methods for fresh and used fuel pins: only the reference test and cladding mechanical properties are modified.

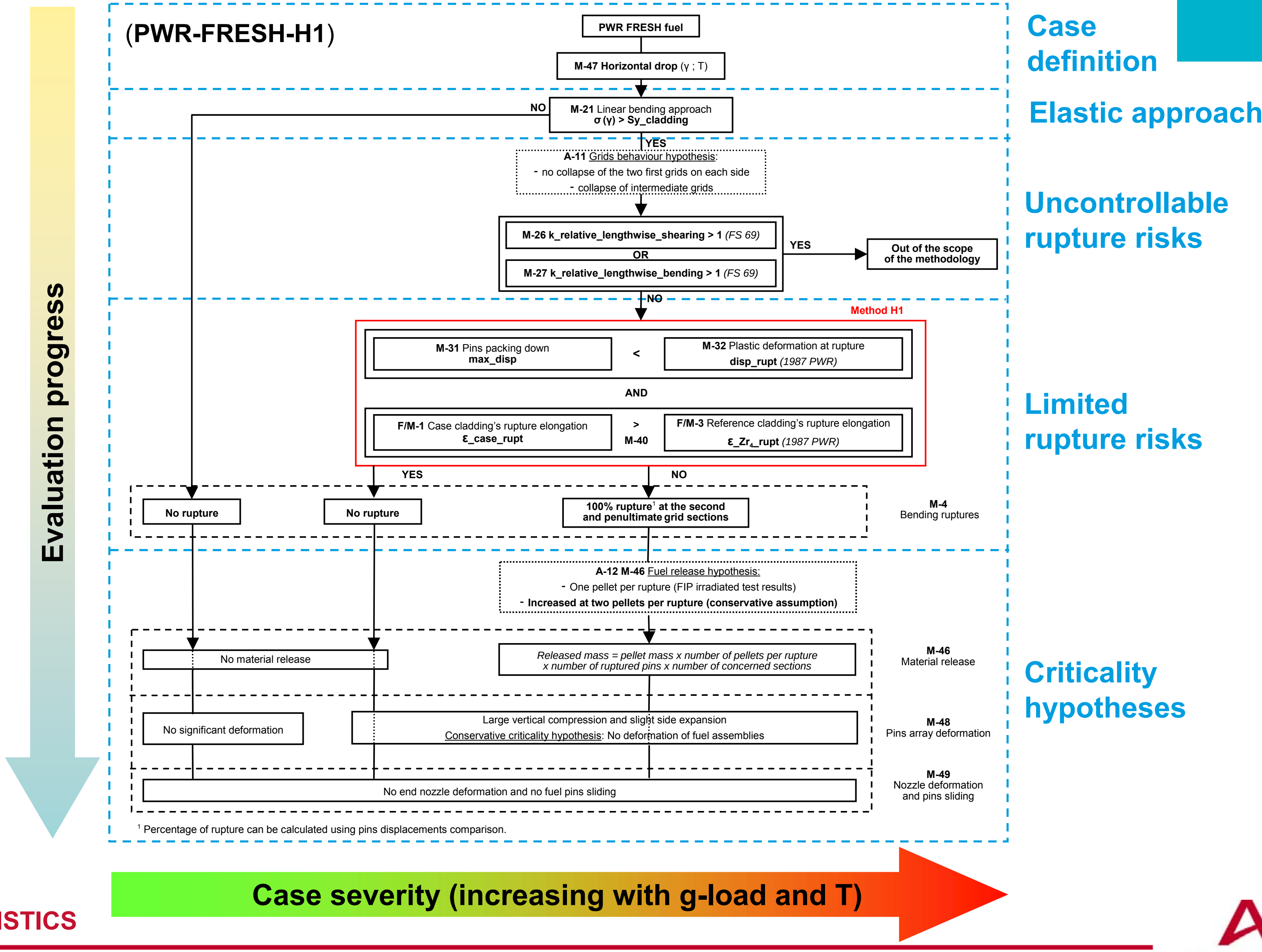
Building FIP Methodology (3/3)

- **Case definition:**
  - Fuel assembly type (PWR or BWR)
  - Drop direction (lateral or axial)
  - Irradiation state (fresh or used fuel)
  - Fuel assembly g-load
  - Cladding temperature

8 combinations (fuel assembly type, drop direction, irradiation state) → **11 flow charts**

Load parameters (fuel assembly g-load, cladding temperature)

FIP Methodology Structure



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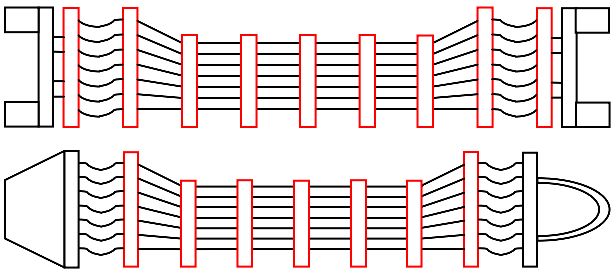
Step-by-step Description: rupture risk evaluation in lateral drop

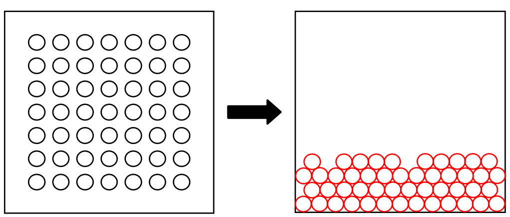
Lateral drop:

PWR
$\gamma \geq 20$ g

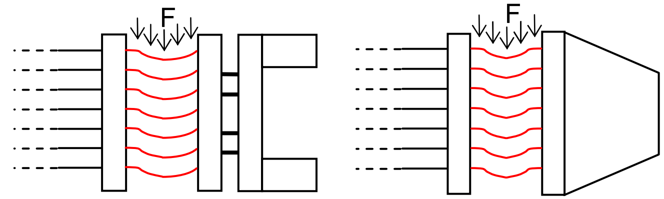
BWR
$\gamma \geq 15$ g



Slight packing down of end grids and complete collapse of central grids

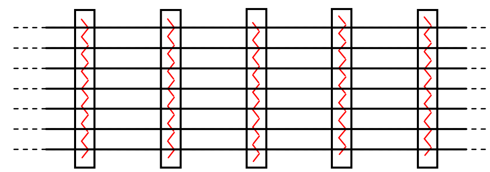


Complete packing down of fuel pin array in the FA central part



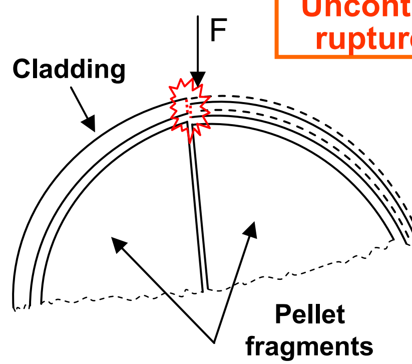
Inter-grid bending

Limited rupture risks

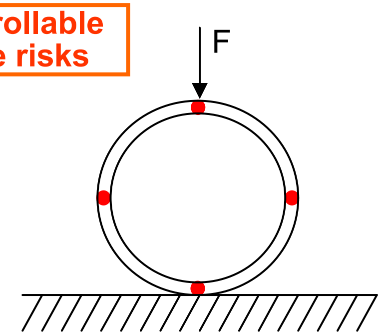


Transversal shearing at grid sections

Uncontrollable rupture risks



Longitudinal shearing on cladding generatrix



Ovalisation

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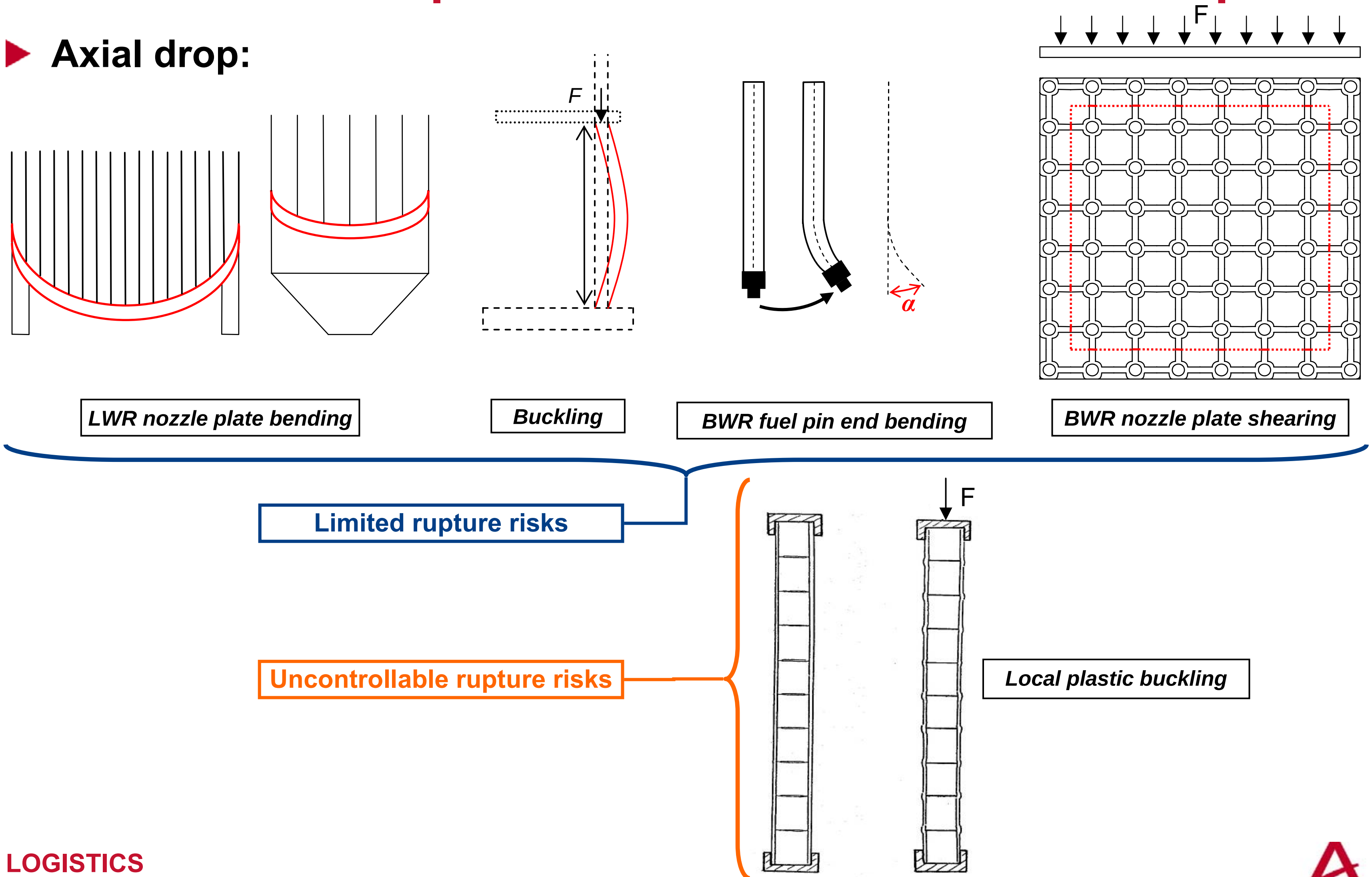
Step-by-step Description: rupture risk evaluation in axial drop

▶ Axial drop:



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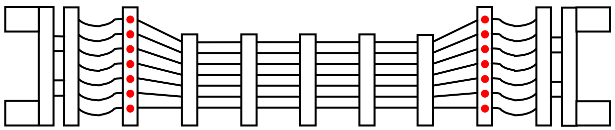
Step-by-step Description: potential ruptures and fuel release

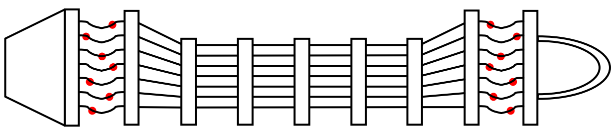
▶ Lateral drop:

PWR



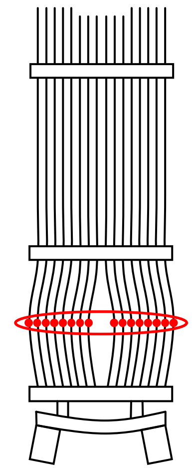
Ruptures at the second and penultimate grid sections

BWR



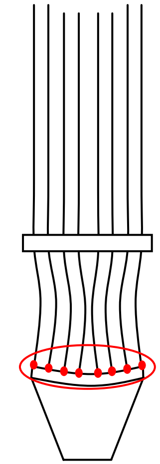
Ruptures along the first and last inter-grid sections

▶ Axial drop:



PWR

Ruptures at mid-span of the lower inter-grid region



BWR

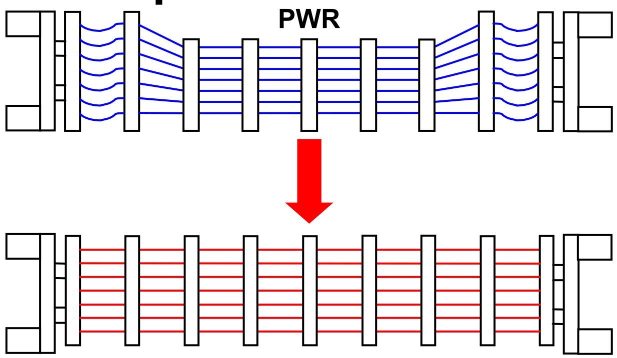
Ruptures at the end of the lower inter-grid region

▶ Amount of fuel released:

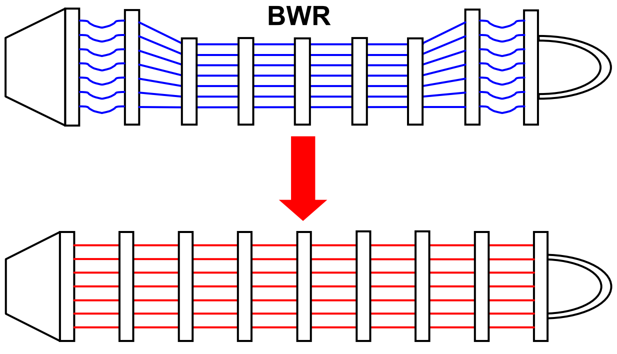
- **Based on the analysis of results from test series 11 & 12, standardised and conservative amounts of fuel released per rupture can be estimated: 1 or 2 pellets per section of broken fuel pin**

Step-by-step Description: array deformations

- **Lateral drop:**



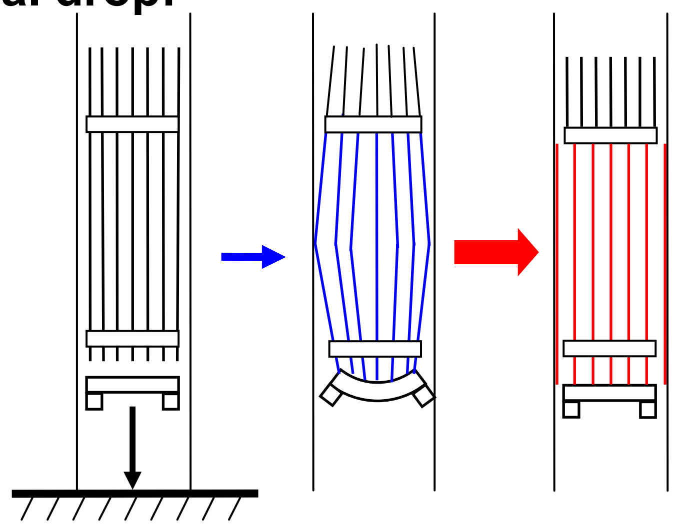
Conservative hypothesis: initial geometry



Conservative hypothesis: initial geometry

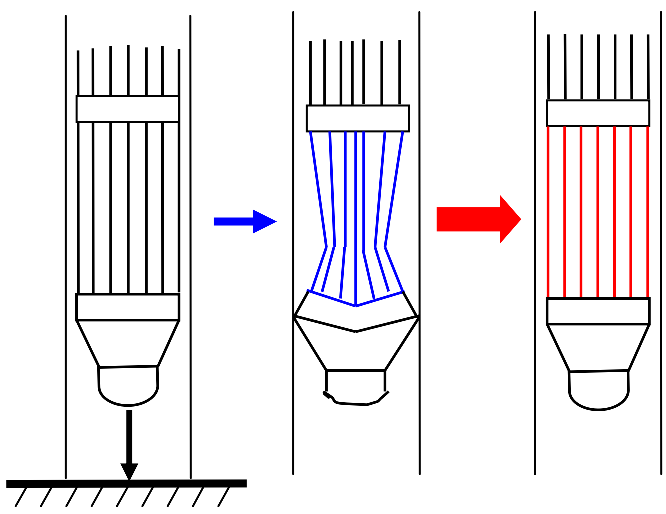
- **Axial drop:**

PWR



Conservative hypothesis: uniform expansion up to lodgement walls in the bottom inter-grid region

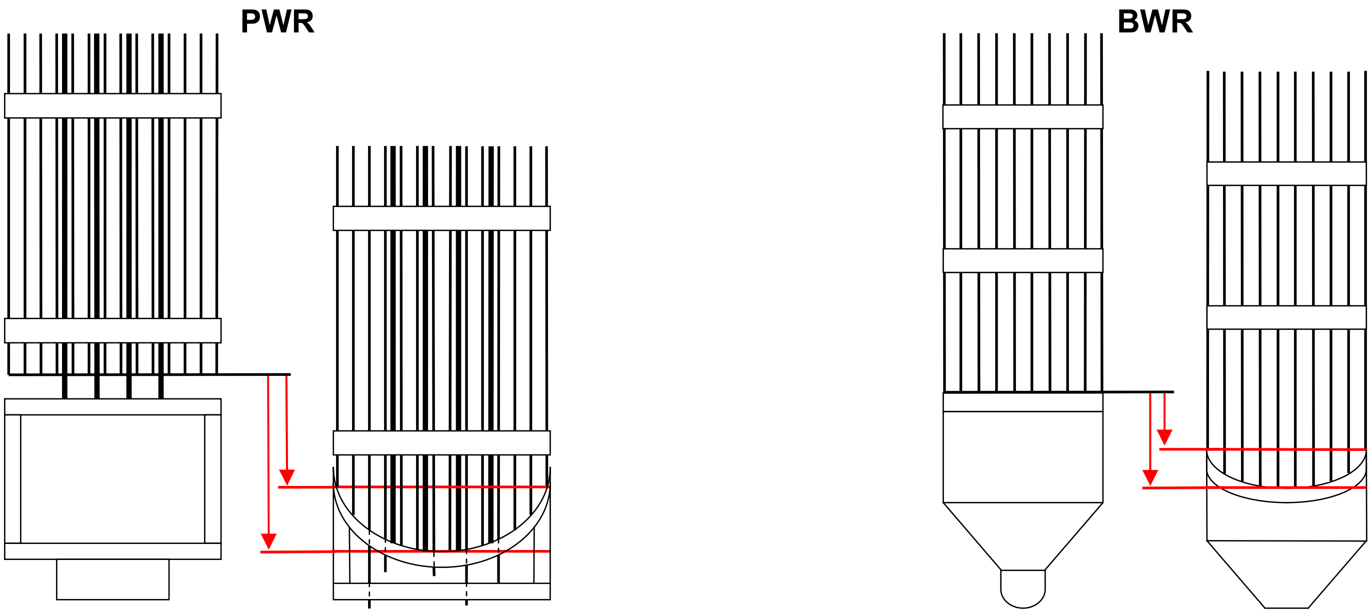
BWR



Conservative hypothesis: initial geometry (Possible expansion in the second inter-grid region)

Step-by-step Description: array displacements

- **Lateral drop:**
  - **No (uniform or differential) sliding → PWR and BWR**
- **Axial drop:**
  - **Closing of gaps between fuel pins and nozzle plate → PWR only**
  - **Crushing of nozzle parts → PWR and BWR (uniform sliding)**
  - **Bending of nozzle plate → PWR and BWR (differential sliding)**



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Conclusion

- **TNI and INS joint effort has led to:**
  - **A better understanding of FA damage in ACT**
  - **A methodology to assess conservatively FA mechanical behaviour**

- **All knowledge acquired in the course of the FIP has been synthesized in the Technical Guide**

  → Submitted to CA at the end of 2008

- **Next step: integration of irradiated cladding brittle fracture risk**

Comprehensive knowledge of FA in ACT