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Reactivity insertions for the Borax accident in ORPHEE research reactor

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Yacine Chegrani*, Florence Gupta, Franck Bernard
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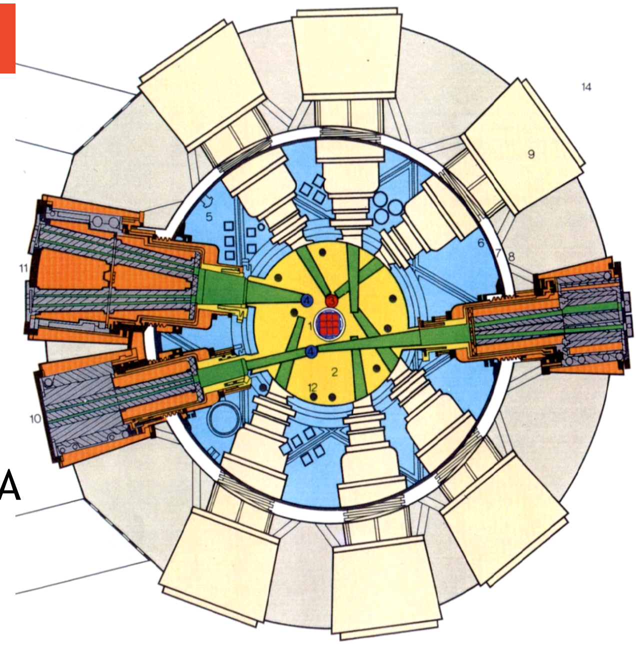
Plan of the Presentation

- **Introduction**
  - Context
  - Safety demonstration provided by the utility

- **IRSN assessment work on RIA**
  - Validation process of IRSN-made ORPHEE model
  - Reactivity insertions evaluation
  - Discussion

- **Conclusions**

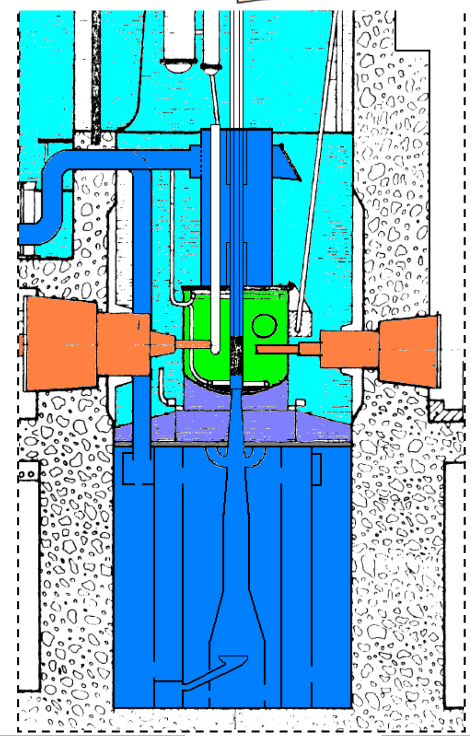
Context of the study



- **Second decennial safety review of French reactor ORPHEE**
  - Open core, pool type reactor built in 1986 by CEA
    - Neutron source reactor, 14MW
    - 8 square subassemblies, plate type fuel, aluminum clad, 93%
    - 9 neutron beam channels
    - 2 reflectors (Beryllium / heavy water)
    - 2 cold sources, 1 hot source in the reflector

IRSN is the technical support to French public authorities

- **Borax = severe reactivity insertion accident**
  - Safety goal: Robustness of the containment building and pool
  - Safety assessment procedure includes:
    - **Reactivity worth of initiating events**
    - Thermal consequences on fuel plates
    - Pressure load on the reactor structures



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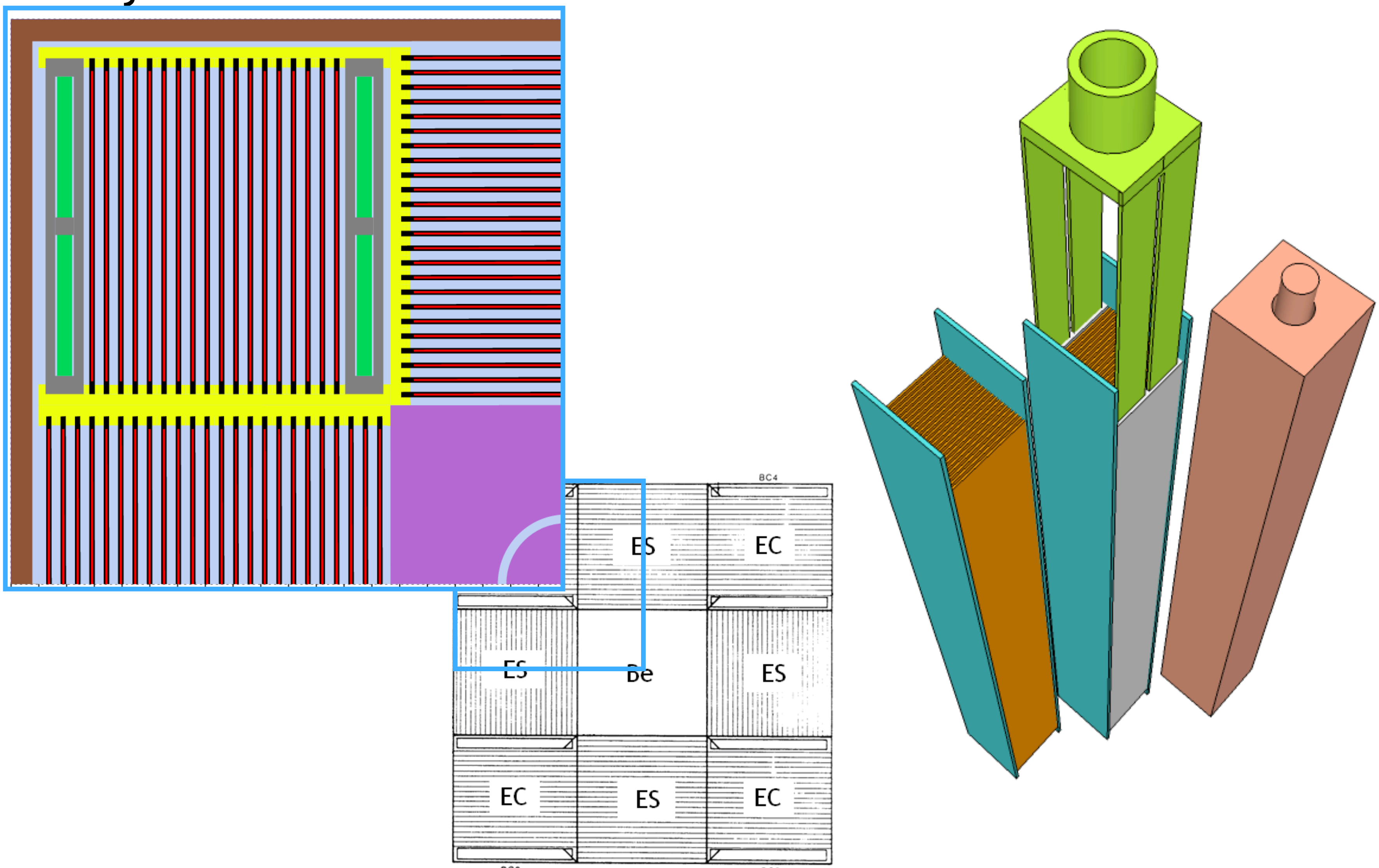
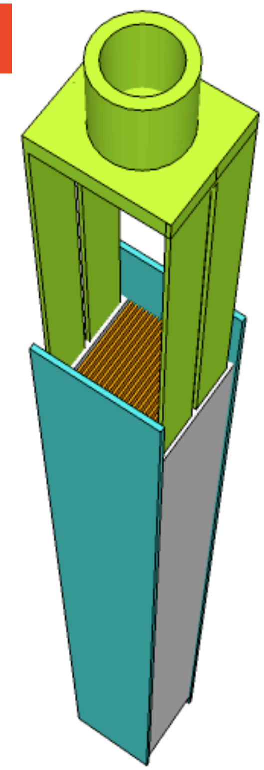
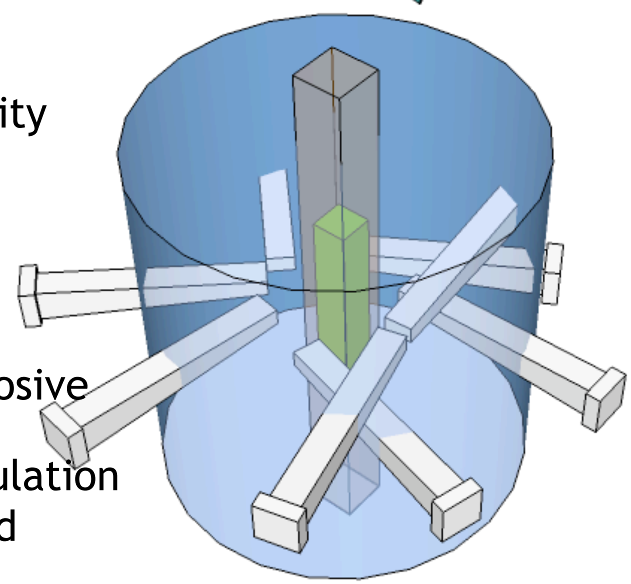
Layout of the core and subassemblies



Safety demonstration for ORPHEE regarding RIA



- **Two main identified initiating events**
  - Control fork excessive withdrawal ➔ ramp insertion
    - No possible ejection (downward flow)
    - Transient protected by scram thresholds and feedback
  - Experimental equipment failure ➔ **instantaneous insertion**
    - Flooding of channels and probes by heavy water: reference case
      - ➔ Less leakage in high flux area
    - Disappearance of channels structure: sensitivity case
      - ➔ Less capture in high flux area
- **Evaluation of the consequences**
  - Reactor period
    - Higher than the experimental period for explosive borax (SPERT threshold at 4ms)
  - Innovative best-estimated thermal-hydraulic simulation
    - Melting temperature of aluminum not reached



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Instantaneous reactivity insertions

Equipment	Reactivity worth in $
Flooding of Cold Source 1	0.21
Flooding of Cold Source 2	0.19
Vaporisation of H2 in Cold Source 1	0.17
Vaporisation of H2 in Cold Source 2	0.11
Flooding of Hot Source	0.20
Flooding of light pipes	0.12
Flooding of 9 channels	0.45
Total of flooding and vaporisation effects	**1.46** (reference)
Structure disappearance of 9 channels	1.22
Total of flooding and structure effects	**2.90** (sensitivity)

Safety demonstration analysis by IRSN

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- **Lines in green have been measured during start-up**
  - Enough confidence in these values
- **Lines in red have only been calculated in 1974**
  - Diffusion calculations with TRIDENT code
  - ➔ Worth making new calculations

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Monte Carlo code MORET.5A1

- Developed for criticality studies by IRSN
  - Continuous energy cross sections
  - Geometrical model uses 3D basic closed shapes in networks
  - Single geometrical modules can be called several times in the geometry
  - Integration of an estimation of kinetic parameters
- Validation procedure set up for this study
  - Comparison between MORET5 calculations and available reference calculated data extracted from the safety report
    - several levels of geometry simplification
  - Comparison with identical model in MCNP
- Kinetic parameters calculation
  - Reliable experimental values, used as complementary indicator

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Validation against the simplified model from design calculations

- **Experimental equipment not simulated**
- **Two distributions of boron are applied**

	No boron (MORET/ MCNP/TRIDENT)	**Homogeneous** (MORET/MCNP/TRIDENT)
Control fork worth in $	40 / 40 / 46	38 / 39 / 42
Critical Height in cm (exp = 58.6 cm)	27 / - / -	50 / 50 / 47
Bcalc/Bexp	0.9 / - / -	0.9 / - / 1
Lcalc/Lexp	1.8 / - / -	1.7 / - / 4.5

- **Good general agreement**

Validation against the available experimental data

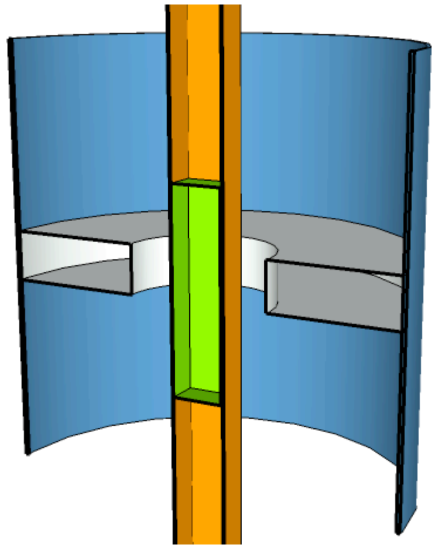
- **Heterogeneous distribution of boron, as it is during operation**

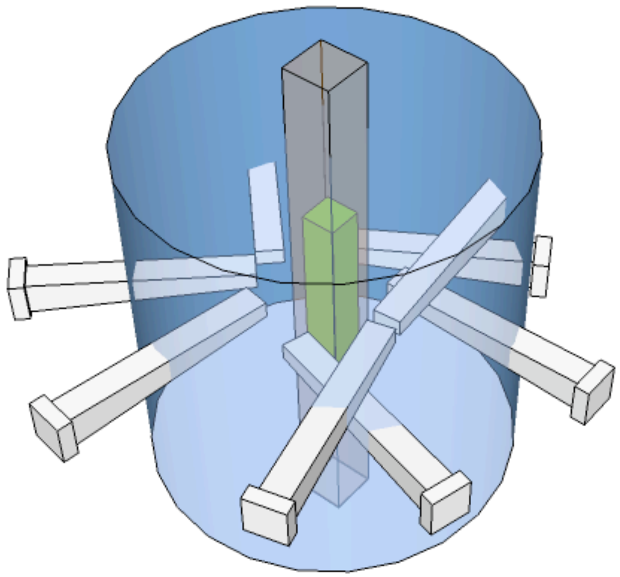
	Heterogeneous (MORET)
Control fork worth in $	37
Critical Height in cm (exp = 58.6 cm)	**58**
Bcalc/Bexp	0.9
Lcalc/Lexp	1.8

- **Better agreement**
- Addition of experimental equipment improves L calculations
  - Dependent on the quantity of heavy water in high flux areas

Calculations of reactivity insertions

- Addition of 9 neutron beam channels
  - Equivalent volume at mid-plan
  - Precise description of each channel





	Reactivity in $ (Ring - IRSN)	Reactivity in $ (CEA 80's)	Reactivity in $ (Precise - IRSN)
Flooding	2.2	0.5	2.1
Structure	0.4	1.22	0.7

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Discussions

- **CEA provided new results obtained with TRIPOLI 4 (Monte Carlo)**
  - Validation against the measured cold source worth
  - 9 Channels reactivity worth evaluation (precise description)

	Reactivity in $ (CEA)	Reactivity in $ (IRSN)
Flooding	**1.7**	2.1
Structure	**1.6**	0.7

- **Discrepancies have been addressed**
  - Flooding: difference in heavy water reflector purity
  - Structure: difference in aluminum thickness

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Conclusions

Equipment	Safety report calculations (80's)	Up-to-date calculations
Flooding of Cold Source 1	0.21	0.25
Flooding of Cold Source 2	0.19	0.15
Vaporisation of H2 in Cold Source 1	0.17	0.12
Vaporisation of H2 in Cold Source 2	0.11	0.11
Flooding of 9 channels	0.45	1.65
Total of flooding and vaporisation effects	1.46	2.66
Structure disappearance of 9 channels	1.22	1.62
Total of flooding and structure effects	2.9	4.3

- **These new values pull the reactor period closer to the experimental threshold**
- **Safety report values will be updated**
  - 2.9 $ will become the reference case, and no sensitivity case will be considered
- **Periodic examinations and replacement schedule of the neutron beams will be modified and tightened to reduce the risk of simultaneous failure**

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Thank you for your attention