SAFETY ISSUES & SAFETY INDICATORS FOR ACCELERATOR DRIVEN TRANSMUTERS WITH DEDICATED OXIDE FUELS

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ADS OVERVIEW

**PDS-XADS (80 MWth – LBE)**

- Subcritical system with excellent safety parameters *(MOX fuel)*:
  - Negative core void worth
  - Low q’, Doppler, kinetics etc.

- Accident investigations reveal benign transient behavior *(not surprisingly)*:
  - Design Basis Conditions
  - Design Extended Conditions
  - Severe Accidents

- Even under DEC or severe conditions - **NO** 'fast or direct' path towards an energetic scenario exists

- Limited discussion on 'consequences' of severe scenarios 😞
ADT OVERVIEW

ADT (800 MWth – LBE)

- Investigations within FUTURE Program (5th FP of EU)
- Dedicated fuels with high MA content + inert matrices (CERCER, CERMET)
- Subcriticality margin ~ 3000 pcm
- Safety analyses of LBE cooled ADTs with dedicated fuels show that:

  THE VOID WORTH MIGHT BE HIGHER THAN SUBCRITICALITY MARGIN

QUESTION:

Do we have to eliminate some fuels (& matrices) a priori from further consideration?
**ADT FUELS**

**Fuel Characteristics of ADTs**

- **Dedicated fuel:**
  - **CERCER:**
    - $(\text{Pu,An,Zr})\text{O}_x$
    - $(\text{Pu,An})\text{O}_x - \text{MgO}$
  - **CERMET:**
    - $(\text{Pu,An})\text{O}_x - 92\text{Mo}$

- **Double tier strategy** to maximize incineration rates characterized by:
  - High MA (Pu) content
  - No fertile material such as U238

- **MAs ⇒ deteriorating impact on:**
  - Fuel thermal-physical properties
  - Core safety parameters

- **Balanced by subcriticality**

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![Graph](image)
Impact on Thermal-Physical Properties

Potential Impact on Safety Related Fuel Properties ((Pu, Am, Cm)O₂):

- Reduced melting point (2600 K)
- Reduced thermal conductivity
- Actinide redistribution (AmO₂)
- Clad corrosion
- Separation/segregation processes
- Helium release!

Composite fuels with improved properties:

- CERCER
- CERMET
Impact on Core Parameters

Characteristics of *ADT* Core Safety Parameters:

- High coolant density & void worth
- High steel worth
- High fuel worth
- Low Doppler
- Low $\beta$-eff
- High helium release potential

- Subcriticality
- High LBE boiling temperature (1943K)
- Thermal structural expansion
More on ADTs Safety

- How should the safety issues be tackled?
- How should the analyses proceed?

Suggestions:

- A complete view of transients: *DBC & DEC*
- A look at *severe transients* within DEC
- Strengthening of preventive safety measures: *elimination of cliff edge effects*

Existing Problems:

- Elimination of subcriticality under core melt conditions (DEC) with deteriorated safety parameters
- Lack of prompt negative Doppler feedback

Power Excursion ‘Cliff Edge Effects’ & Potential Mechanical Disassembly
DEC Scenario with Pin Potential Damage & Failure Propagation

1. **Intact core**
2. **Local pin-disruption**
3. **Spread of disruption**

- Pump coast-down, Channel blockage
- Can-wall breakup

**Sequence of Events**:
- Plenum-gas leak through crack (gas blowdown)
- Clad melting (bubble & molten-steel release)
- Fuel particle release
Activation of Reactivity Potentials

**Void Worth Potential:**
- Activated via clad failure and blow-down of fission gases and He
- Clad failure before melting
- Leading in time sequence
- Overpower and under-cooling transients

**Steel Worth Potential:**
- Steel melting before coolant boiling
- Activated via under-cooling transients
- Unclad pin stubs

**Fuel Worth Potential:**
- Dominating after fuel mobilization
- Dispersal versus compaction (recriticality)
- 'If' floating under Pb/Bi conditions - where?
A closer look at: **Kinetics & Feedbacks**

**Doppler:**
- Stabilizing feedback
- Important under severe conditions (criticality) as only prompt negative feedback mechanism before mechanical core disassembly

**Structural expansion:**
- Axial expansion of fuel under transient conditions unknown (fuel/clad dominated?)
- Core (clamping, pads) and grid-expansion design-dependent

**Kinetics parameters:**
- Small beta-eff
- Potential reduction of neutron generation time

Interaction?
Impact of Void on Accident Development I

ULOFO SCENARIO for a CRITICAL Sodium Cooled Reactor

1. Pump coast down
2. ‘Na’ heat up & positive reactivity feedback
3. Doppler
4. Axial fuel expansion
5. Boiling and void release
6. Clad and fuel motion
7. Fuel motion (dispersal) reactivity dominates

Void Worth Potential of ~ + 5-7 $ NOT - consumed!
(timing)

If Void/Doppler Ratio ~ – 3
No severe energetic scenario
Critical Fast Reactor Cores

SAFETY PARAMETERS

<table>
<thead>
<tr>
<th></th>
<th>Monju</th>
<th>SNR 300</th>
<th>CAPRA 4/94</th>
<th>EFR CD/91</th>
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<tr>
<td>Power MWth</td>
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<td>Coolant worth pcm</td>
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<td>1990</td>
<td>2322</td>
<td>1687</td>
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<tr>
<td>Doppler-wet pcm</td>
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<td>-723</td>
<td>260</td>
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<td>(Void/Doppler-wet)</td>
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<td>-1.3</td>
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<tr>
<td>Beta-eff pcm</td>
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<td>347</td>
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<tr>
<td>Neutron generat. time 10^{-7} s</td>
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Typical reactivity potentials, Doppler constants and kinetic parameters for various critical fast reactors

(extensive safety investigations performed for most of these cores)

Proven Safety Case
(first 6 cores)
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### Void/Doppler Ratio

~ -1600 ÷ +900!

**LMFR**

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Impact of Void on Accident Development II

ULOФ SCENARIO for a SUB-CRITICAL LBE Cooled ADT

1. Positive reactivity feedback with approaching criticality
2. No Doppler
3. Axial fuel expansion
4. Heat-up of coolant (and fuel)
5. Pin/clad failure
6. Gas blow-down
7. Void reactivity driven excursion
8. Clad removal
9. Fuel dispersal

N.B.:

- Empirical reasoning deduced from critical reactor experience
- If fulfilled the ADT should not suffer from severe accident developments
- Criterion does not exclude core melting

SAFETY INDICATOR:

\[ SI = \frac{\text{core-void} + \Theta \ast \text{clad worth}}{\text{subcriticality} + \text{Doppler}} \]

\[ SI \sim -3 \]
Safety Indicator for ADT Cores II

\[ SI = \frac{\text{core-void} + \Theta \cdot \text{clad worth}}{\text{subcriticality} + \text{Doppler}} \]

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Clad Worth?:

\(~3000\) pcm (most promising fuels & cores investigated within FUTURE)

QUESTION:

IS THIS SAFETY INDICATOR VALID FOR ADT SAFETY ANALYSES?
Severe ADT Transient

DEC ULOF with Dedicated Fuel

Example 1:
1200 MWth ADT
(SIMMER-III Code Simulation)

Example 2:
800 MWth FUTURE ADT (ZrO₂ Matrix)
(SIMMER-III Code Simulation)

\[ \text{SI} \sim -4 \]

\[ \text{SI} \sim -2 \]

CONCLUSIONS?
SAFETY INDICATOR ISSUES

PROBLEM OF VOID & CLAD WORTH

Position 1: **Restrictive Approach**
- Discard cores with void worth potentials (clad worth potentials) larger than subcriticality margin from further consideration.
- Accept restrictions given by this requirement on fuel, core-size, design, p/d ratio etc.

Position 2: **New (more tolerant) Criterion**
- A SI is formulated, which should comply with a pre-set criterion

**PLEASE NOTE:**
1. This is a proposal for discussion
2. Further extensive testing is needed
3. Optimization of design still necessary
Core Size Sensitivity Analysis

**Investigate whether a reduction in core size would be beneficial from a void/safety point of view**

- **Void ρ vs. Δ Radius**
- **Void ρ vs. Δ Volume**

- **Void Worth Still Higher than Subcriticality**
- **Marginal Gain**
- **Cost/Benefit Analysis Necessary (ADT in scenario)**
CONCLUSIONS

Remarks

- LBE cooled ADS -> very good safety behavior
- ADTs arise some safety concerns

REACTIVITY POTENTIALS LARGER THAN THE SUBCRITICALITY MARGIN

- Restriction to the fuels & designs where subcriticality would cope with reactivity potentials might

SEVERELY LIMIT DESIGN FLEXIBILITY

Safety Indicator (SI)

- Allows some relaxation on more traditional safety requirements
- Aims at excluding severe accidents with energetics

Open Issues

- Empirical proposal must be CHECKED & PROVEN
- Investigation of supporting measures
  (e.g.: in-pin orifices, axial absorber layers, shutdown systems, 3rd shut-down level (EFR) etc.)
- Reduction of Core Size

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THANK YOU!

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