Consideration of DEC in the context of modular HTR

Fu LI
INET, Tsinghua University, China
lifu@tsinghua.edu.cn

9 - 11 December 2019
IAEA Headquarter, VIC
Outlines

1. DEC in IAEA SSR 2/1
2. Features of modular HTR
3. Typical DEC for modular HTR
4. Requirement for DEC for modular HTR
DECs are accident sequences that frequency is lower than DBA, and consequence may be worse than DBA, and should be considered in design.

- With some cutting off
- My interpretation
For LWR in IAEA SSR 2/1, the assumption is logical

- DEC includes sequences without core damage, and with core melt
- Sequences without core damage is nearly nothing, strict acceptance criteria can be setup
  - Outside of these sequences can be classified into core melt
  - Worse consequence of these sequences can be enveloped by core melt?
  - Countermeasures as 3\textsuperscript{rd} or 4\textsuperscript{th} level of DiD?
  - Safety features or not?

- Sequences with core melt cover many conditions
  - Core melt will be assumed, despite of the frequency (~1E-4? 1E-6? 1E-7?)
  - This is the real concern for DEC
1. DEC in IAEA SSR 2/1

- For LWR in IAEA SSR 2/1, the assumption is logical
  - Containment integrity is important for DBA and DEC
    - To confine the radioactive, to preserve coolant for fuel cooling
    - Leak-tight containment is the typical design
  - Safety features are required to prevent and mitigate DEC, or specifically the core melt, as 4th level of DiD
    - It is additionally required other than safety system, it is logically required to be independent from safety system as much as possible
    - As safety class in future?
    - Independ from safety system is logical
  - Failure of containment is handled by 5th level of DiD
    - The frequency will be analyzed
    - ~1E-7? 1E-8?
2. Features of modular HTR

- Inherent safety is required, or can be achieved by modular HTGR
  - Large scale of fuel failure, or core melt, can be, or must be, physically, or practically, eliminated
    - By high quality TRISO fuel, dedicated reactor design
  - The accident sequence progresses very slowly
    - Long grace time, high availability for countermeasures
  - Almost all radioactive is confined in TRISO coated particle, under all accident conditions
    - Higher requirement for fuel and reactor design is required
    - Leak-tight containment is not necessary
    - Mitigation must/can be provided to reduce the release as low as reasonably achievable (ALARA)
2. Features of modular HTR

- Accident sequences that frequency is lower than DBA, and consequence may be worse than DBA, and those should be considered in design, can also be named as Design Extension Conditions (DEC) for modular HTR
  - In HTR-PM project, it is named as selected Beyond Design Basis Accident (BDBA)
  - No core melt will be assumed, or must be practically eliminated
3. Typical DEC for modular HTR

- Typical sequences in HTR-PM
  - SBO
  - ATWS
  - Failure of RCCS
  - Failure of SG dump system (larger water ingress)
  - Air ingress (break of two helium tubes)
  - Failure of trip of helium circulator
  - ...

3. Typical DEC for modular HTR

- **Countermeasure for DEC**
  - After the actuation of safety system, long term actions includes:
  - Manual drop of control rod or small absorber ball system
  - Filtration of the reactor building via sub-atmosphere ventilation system
  - Cooling of reactor via accident purification train of helium purification system
  - Removal of humidity from primary circuit via accident purification train of helium purification system
  - Cooling of reactor via main heat transfer system
  - Control of pressure/inventory of primary circuit via helium supporting system
  - Other accident management (to repair the components, to isolate the primary circuit, to restart the reactor, other temporal actions, to fill the reactor building with Nitrogen, ...)

...
3. Typical DEC for modular HTR

- **Release for DEC**
  - **No large scale failure of fuel is expected**
    - Temperature criteria for fuel is not challenged
    - Water ingress and air ingress did not really challenge the integrity of fuel particle
    - Measures to limit the air ingress and water ingress is required to be provided
  - **No additional failure of safety SSC is expected**
  - **Isolation of primary circuit, filtration on reactor building will be very effective to reduce radioactive release**
    - Leak-tight containment is not necessary
    - VLPC works very well
3. Typical DEC for modular HTR

- Release for DEC
  - With the help of long grace time, the availability of these mitigation features can be very high
  - The release for these DEC sequences is limited
    - Even with some conservative assumption in HTR-PM project
4 Requirement for DECs for modular HTR

- HTR can use the terminology of DEC
  - Its frequency is lower than DBA
  - Its consequence may be worse than DBA
  - The scope to be considered must be limited
    - Maybe by cutting off frequency, or engineering judgement
    - How lower the cutting off frequency?
4 Requirement for DECs for modular HTR

- No fuel damage or core melt is expected or allowed
  - Higher requirement for fuel and reactor is expected
  - The acceptance criteria for DEC may be different from the DEC without core damage in LWR
    - 10mSv is setup for same LWR/SMR projects in China
    - Probabilistic safety goals is more reasonable for modular HTR, because of lower frequency for some DEC sequences
      - 10mSv may be difficult to achieve for some sequences with very low frequency, selected by engineering judgement
    - It is not a good idea to treat DEC (without core melt) as another group of DBA
## Requirement for DEC

**Plant states considered in the design, IAEA SSR 2/1**

<table>
<thead>
<tr>
<th>Operational states</th>
<th>Accident conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal operation (NO)</td>
<td>Design extension conditions (DEC)</td>
</tr>
<tr>
<td>Anticipated operational occurrences (AOO)</td>
<td>without significant fuel degradation</td>
</tr>
<tr>
<td>Design basis accidents (DBA)</td>
<td>with core melt</td>
</tr>
</tbody>
</table>
## Requirement for DEC

**DEC for mHTGR**

### Accident conditions considered in SSR 2/1

<table>
<thead>
<tr>
<th>Operational states</th>
<th>Accident conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO</td>
<td>AOOS</td>
</tr>
<tr>
<td>NO</td>
<td>AOOS</td>
</tr>
</tbody>
</table>

- **No severe accident (with core melt) for modular HTGR/VHTR**
- **The cutting off frequency should be addressed as the residual risk**

### DEC for mHTGR

- **Residual risk** / Practically eliminated without significant fuel degradation

---

**INOT**
4 Requirement for DECs for modular HTR

- **No specific measures to prevent and mitigate the core melt**
  - Safety feature is not a proper terminology in the context of modular HTR
  - Mitigation systems to reduce the release, to mitigate the consequence, is still required, according to ALARA principle, mitigation feature is a term to be used
  - Or design features?

- **Mitigation features can be operating, or supporting systems,**
  - The requirement of independence from safety system is not applicable
  - Actually safety systems are also important for DEC
4 Requirement for DECs for modular HTR

- The 4\textsuperscript{th} level of DiD may be different
  - Prevention & mitigation of core melt vs. to reduce release
  - Independence with 3\textsuperscript{rd} level may have different meaning
  - It will be conflict with definition of DiD level 3A, 3B & 4 in some LWR cases
    - More consistence with definition of DiD level 3, 4A & 4B for LWR (without 4B in case of HTR)
  - Although the sentences for DiD in SSR 2/1 is not changed yet
Conclusion remarks

During the development safety design criteria for modular HTR based on IAEA SSR 2/1, DEC is also adopted, but

- No core damage, or core melt is assumed
- Higher requirement for fuel and reactor design is required
- Cutting off frequency may be required (how low?)
- Safety features has different purpose, new terminology of mitigation features can be used (or design features?)
- leak-tight containment is not necessary
- Integrity of containment is not applicable
- Acceptance criteria for DEC may need special consideration, comparing with DEC without core damage in LWR, probabilistic safety goal is more reasonable

More like BDBE

Definition of DiD level 4 need more consideration
Thanks for listening &
Thanks for comments!