Review of the Safety Concept for Fusion Reactor Concepts and Transferability of the Nuclear Fission Regulation to Potential Fusion Power Plants

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Overview

Achievement

Literature survey of the **fusion safety concept,** based on:

- Safety and Environmental Assessments of Fusion Power (SEAFP)
- Safety and Environmental Assessment of Fusion Power - Long Term Programme (SEAL)
- Power Plant Conceptual Study (PPCS)
- Licensing documentation of the ITER project and ITER safety and licensing update

Exemplarily checked against **German safety requirements for nuclear power plants**

Current Status

- **Fusion safety concept** based on the concept of **defence in depth**, **necessary to guarantee** the confinement of the radioactive inventory
- In principle, the (German) **safety requirements** for **NPPs** can be applied to **FPPs**. Specific differences between the implementations of the safety concept of FPPs and NPPs exists

Next Steps

Together with an increased level of detail of the plant designs of future FPPs

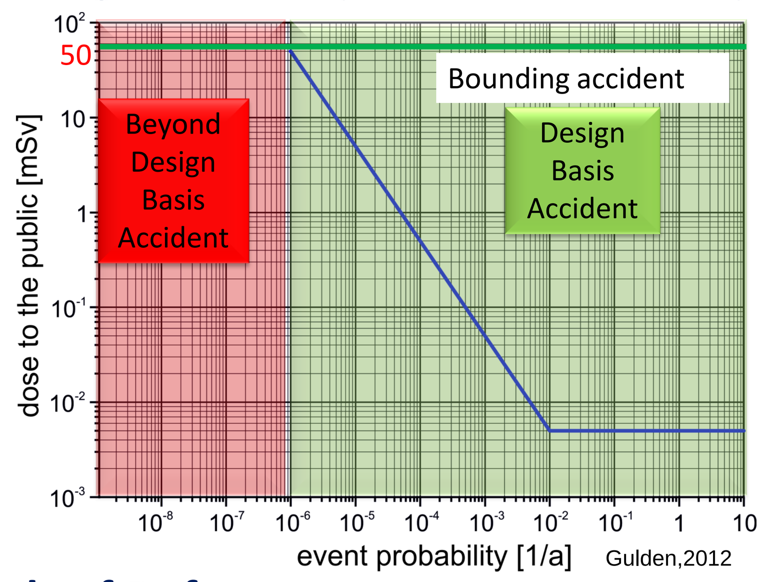
- a **systematic assignment** of measures and installations to the different **levels of defence**
- **potential releases**
- **external events** (e. g. earthquakes and flooding) and very rare **man-made external hazards** (crash of a large air plane)

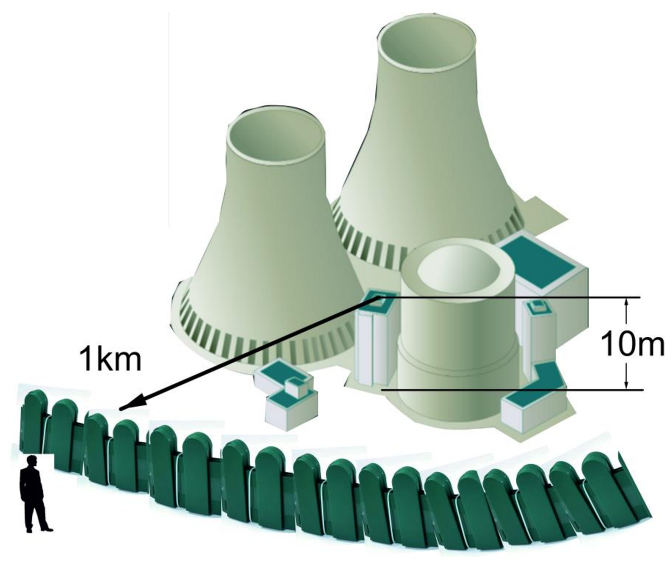
have to be analysed in more detail

Fusion Safety Approach

Safety concept of fusion based on **five levels of defence** [INSAG-10]

Radiological Consequences versus Frequencies





Levels of Defence

LoD	Operational state	Objective	Means	Consequences dose limit
1	Normal operation	Prevention of abnormal operation and failures	Conservative design high quality in construction, operation	No measure
2	Anticipated operational occurrence $f > 10^{-2}$/a	Control of abnormal operation and detection of failures	Control, limiting and protection systems and surveillance features	Plant shall return to full power in short term (after fault rectification)
3	Design basis accident (DBA) $10^{-2}/a > f > 10^{-4}/a$	Control of accidents within design basis (unlikely events)	Engineered safety features and accident procedures	Plant shall return to full power after inspection, rectification & requalification 5mSv/event
4	Beyond design basis accident $10^{-4}/a > f > 10^{-6}/a$	Control of severe plant conditions incl. prevention of progression and mitigation of consequences	Complementary measures and accident management	Plant restart not required 50mSv/event
5	Post severe accidents $f < 10^{-6}$/a	Mitigation of radiological consequences (release of radioactive materials)	Off-site emergency response	Plant restart not required

Identification of Postulated Initiating Events

PIEs identified with different methods (e. g. **Hazard and Operability**, **Master Logic Diagram**, **Functional Failure Modes and Effects Analysis**, **FMEA**)

Similar as in NPPs, e. g.

- loss of flow accidents
- loss of offsite-power, station blackout
- leaks (VV, primary cooling system)

Fusion specific events, e. g.

- loss of cryogenic system
- arcing
- magnet system faults

Event Sequences of Incidents and Accidents, Consequences

PPCS: (overall early MEI doses): about 1.7 µSv for DBA, about 0.16 mSv (model A), 0.4 mSv (model B and AB) for BDBA, 1.16 mSv (model A) and 18 mSv (model B) for the 'bounding accidents'
ITER: (overall early MEI doses): less than 10 µSv for DBAs, 1.1 mSv for BDBAs

Precautionary, Preventive and Mitigative Measures

Primary safety functions

- confinement of radioactivity
- control of operational release
- limitation of accidental release

Secondary safety functions

- Terminate nuclear reactions
- Ensure decay heat removal
- Controlled chemical, magnetic, and thermal discharge
- Limitations of release to ambient

Confinement systems depend on the coolant selected for the in-vessel components and are based on **different structural barriers** and **active systems**

Comparison of the Nuclear Fission Safety Concepts with the Fusion Safety Concept

Based on **German safety requirements for NPPs** ("Sicherheitsanforderungen an Kernkraftwerke", SiAnf)

Enveloping Event

A complete destruction of all confinements of a FPP could result in doses to the public in the order of 1 Sv (several orders of magnitude lower than those for equivalent hypothetical worst-case scenarios of NPPs)

➡ Without safety concept radiation protection measures could be necessary outside of the FPP

Comparison Fission/Fusion Safety Concepts

Reactivity Control, Fuel and Inventory

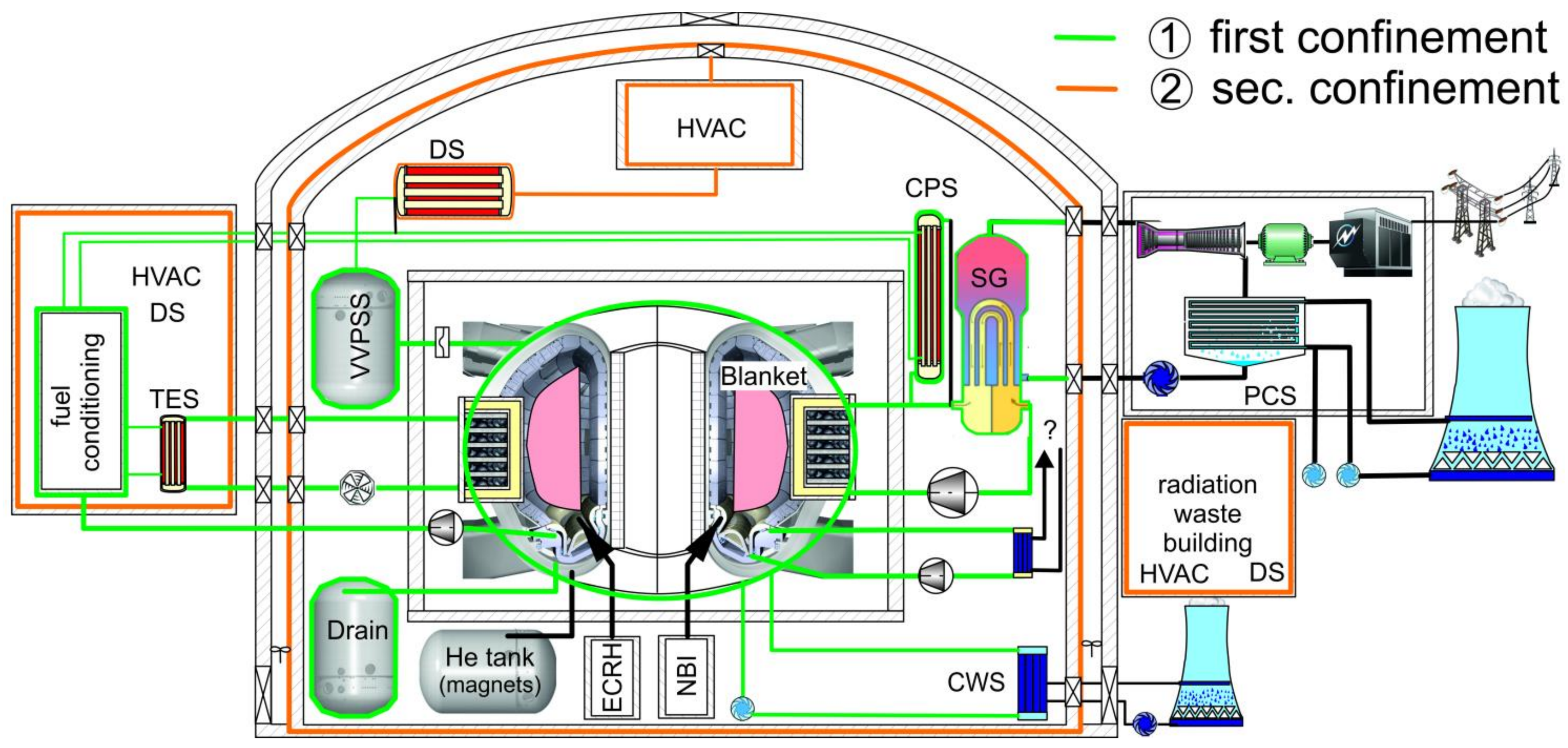
NPP: Necessity to **control reactivity** and **prevent re-criticality**
FPP: **Excursions** of the reaction rate can be **excluded** due to **inherent features** of the design

SiAnf applicable: x **control of reactivity**
✓ **shutdown** of the facility under any circumstances

Barriers

NPP: **Multiple barriers** on several consecutive levels of defence
FPP: Inventories **not concentrated locally**, **active retention functions** like detritiation systems

SiAnf applicable: ✓ **physical barriers and retention systems**



Defence in Depth and Independence of Levels of Defence

NPP: Safety functions ensured by **multiple installations related to different levels of defence**
FPP: General safety concept exists (based on the concept of levels of defence)

SiAnf applicable: ✓ **assign the safety functions** of a FPP to certain level(s) of defence, **if plant design will be available**

Beyond Design Basis Accidents

NPP: Two levels of defence of the safety concept deal with selected **multiple failure events** and **postulated core melt accidents**
FPP: The current safety concept of FPPs covers in the **fourth level of defence** the control of severe conditions and in the fifth level the mitigation of radiological releases

SiAnf applicable: ✓ consider special accident sequences, accident phenomena, and the need for specific accident management measures

External Events and Very Rare Man-Made External Hazards

NPP: Safety analyses incorporate analyses of the impact of **external events**
FPP: **ITER** safety analysis includes **external events**

SiAnf applicable: ✓ to be covered in the safety **concept of on-going DEMO**

First of Its Kind

NPP: P**roven technologies, qualified materials, validated calculation methods** for the safety demonstration based on operational experience
FPP: M**inor operational experience** is available

SiAnf applicable: x **evaluation of the operation experience**

Cooling

NPP: **decay heat has to be removed** to avoid **fuel element damage** and **break of barriers**
FPP: **decay heat of in-vessel components** at EOC (blanket, divertor, etc.)

SiAnf applicable: ✓ means for decay heat removal required

Leak Before Break

NPP: guaranteed the **component integrity** by applying the "leak-before-break concept"
FPP: LBB concept cannot be assessed currently

SiAnf applicable: ✓ depending on **coolant** and **plant design**

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References

As given in the accompanying paper **SEE/P5-12**

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