Review of Generation III Reactors

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Status of Nuclear Power Today (I)

- Future of nuclear power – uncertain.
- No significant growth is to be expected in the next two decades.

BUT:

In the last years, there have been new activities.

There are new NPP projects worldwide – including EU.

Status of Nuclear Power Today (II)

NPPs under construction in European Union:

- Olkiluoto 3 (Finland)
- Flamanville 3 (France)
- [Mochovce 3+4 (Slovakia)]

NPPs more or less firmly planned in EU (and CH):

- 3 further new units in Finland (Olkiluoto 4, Loviisa 3, ??)
- 3 new units in Switzerland (Beznau, Gösgen, Mühleberg)
- Cernavoda 3+4 (Romania)
- Temelín 3+4 (Czech Republic)
- Ignalina (Lithuania)

What is Generation III?

According to the proponents of nuclear energy, reactors of Generation III are characterized by:

- Standardized, simplified, robust design
- Higher availabilities and longer service life
- Yet higher safety
- Yet lower probability of a core melt accident
- Require less fuel, produce less radioactive wastes

-- compared to current reactors (Generation II).

Examples for Generation III Types:

Pressurized Water Reactors (PWR)

- EPR – European PWR (AREVA)
- AP 1000 – Advanced Passive PWR (Westinghouse)
- VVER-1200 – Advanced VVER (Rosatom)
- APWR 1700 – Advanced PWR (Mitsubishi Heavy Ind.)

Boiling Water Reactors (BWR)

- ABWR – Advanced BWR (General Electric/Hitachi)

Heavy Water Reactors (HWR)

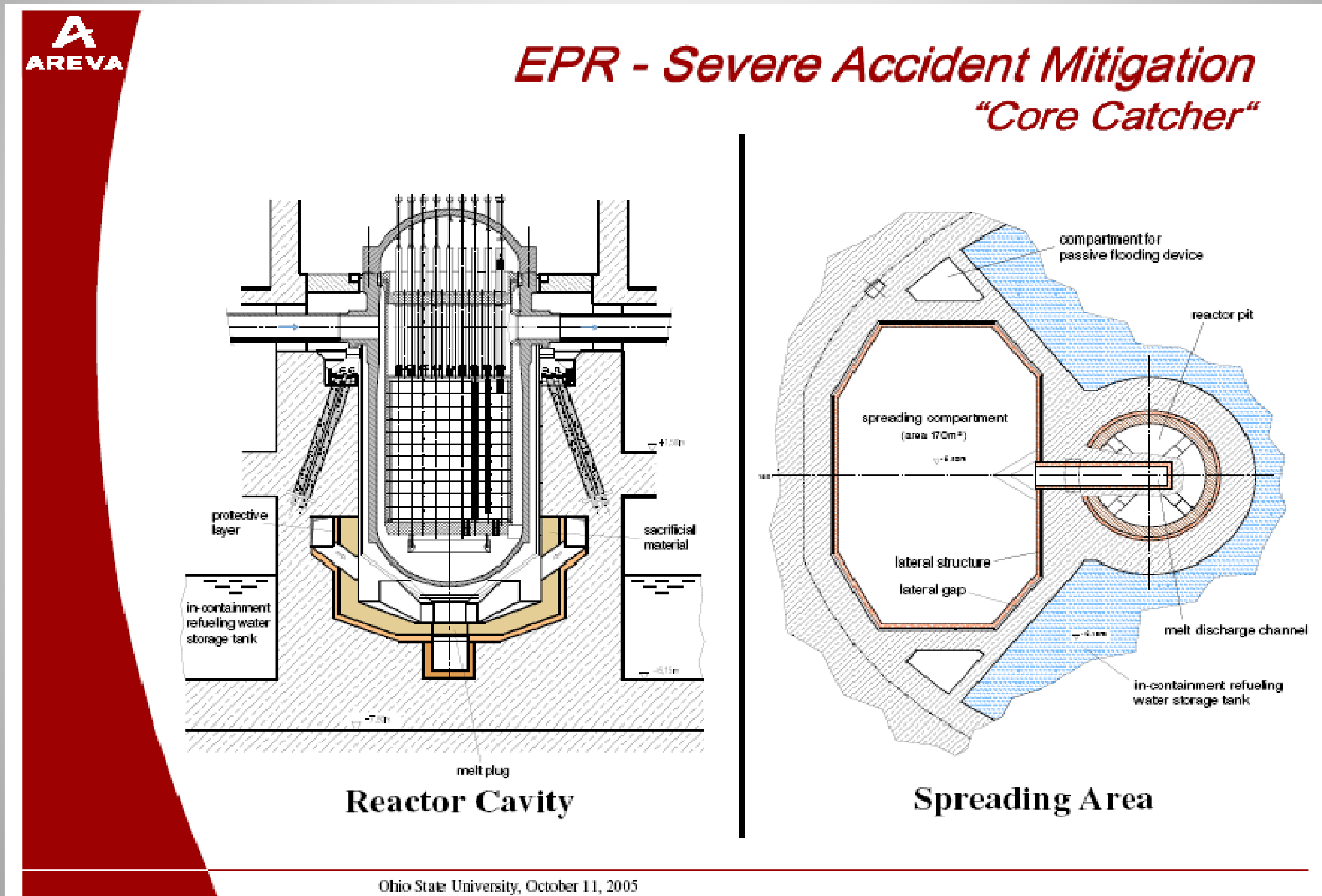
- ACR 1000 – Advanced CANDU Reactor (AECL)

Perceived Safety Advantages of EPR

The following features of EPR are celebrated:

- “Core catcher” to control the effects of a severe accident (core meltdown)
- Strong reactor building (able to resist crash of commercial airliner)
- Many diverse and redundant safety systems

EPR Core Catcher: Design



EPR Core Catcher: Problems

- Reactor pit has to be dry to avoid steam explosion which could damage containment.
- Interaction between molten core and concrete cannot be accurately simulated.
- There are considerable uncertainties regarding heat transfer rates.
- Cracking of the concrete surface can occur; this has not been studied systematically so far.
- Further complication: H_2 generation.

EPR Reactor Building: Design

- Double concrete shell
- Thickness of outer shell 90 cm – 130 cm
- Thickness of inner shell 130 cm. Inner shell with steel liner

Assumptions for airliner crash:

- Boeing B747 at 125 m/s
- Kerosene fire 30 min, 800° C

EPR Reactor Building: Limits

Load assumptions are optimistic:

- Impact velocity can be higher (e. g. 175 m/s)
- Kerosene fire can last hours and reach more than 800° C

The protection of EPR is roughly equivalent to that of German „Konvoi"-PWRs → only partial protection against attack with commercial airliner

EPR Safety Systems

- There is a simplification in the emergency cooling system – coolant storage and sump function are combined in one tank. This is likely to lead to a small improvement in overall safety.
- All in all, however, apart from core catcher and this tank, EPR is roughly comparable to German Konvoi or French N4 plants.
- EPR relies on active safety systems, like Gen II.

EPR Probability of Severe Accidents (I)

Temelín 3+4 EIA Scoping Document:

- Probability of core melt $< 10^{-6}$ /yr

Olkiluoto 3 and Flamanville 3 EPRs:

- Probab. of core melt 1.33 – 1.8 x 10^{-6} /yr

German KONVOI (Generation II) PWR:

- Probab. of core melt in range 1 – 2 x 10^{-6} /yr

EPR Probability of Severe Accidents (II)

Conditional probability of containment failure in case of core melt:

- **0.15** for EPR
- **0.27** for KONVOI PWR

(Difference is less than a factor of 2.)

[Digression on Accident Probabilities as Calculated in PRAs (I)]

There are factors which cannot be incorporated in PRAs, in principle:

- Unexpected plant defects.
- Unforeseen physical or chemical processes.
- Malevolent human behavior (sabotage, terror attacks, acts of war.
- Ageing phenomena can only be incorporated in PRAs in retrospect.
- Complex forms of human error are extremely difficult to model.
- Due to the complexity of an NPP, some accident initiators or sequences are simply bound to be overlooked or omitted.

Even many factors incorporated are beset with considerable uncertainties:

- External events like earthquakes.
- Prediction of the containment behavior.
- Modelling of dependent failures.
- Measures of „accident management".

[Digression - Unforeseen Process]

[Digression on Accident Probabilities as Calculated in PRAs (II)]

Hence – beware of statements of the kind "one accident in a million years"… do not take them at face value!

HOWEVER – PRA results have their uses, for checking a plant design for likely accident contributors, and for comparisons between plants (if the same methods are applied).

EPR Probability of Severe Accidents (III)

Compared to latest Generation II plants, the core melt probability of the EPR is not lower.

And the probability for large releases due of containment failure is, at best, slightly lower – (if the core catcher will function as planned!).

→**No dramatic improvement regarding accident probabilities!**

Other Generation III Reactor Types

- ❖ Other Gen III types of comparable power, and also relying on active safety systems (like the VVER-1200), are likely to be at a safety level comparable to that of EPR.
- ❖ Smaller reactors have certain safety advantages (e.g., option of core melt cooling inside reactor vessel) – but they are not favored.
- ❖ Plants with passive safety systems generally look better – but they only exist on paper so far. New problems can turn up in course of realization…

Conclusion

- The reactor types of Generation III which are farthest in their development do not really add a new dimension to nuclear safety. Their standard is roughly equivalent to that of the latest Generation II plants.
- Reactor types of Gen III with more innovative features exist – but only on paper, so far.

Conclusion (Short Version)

Don’t get excited about Gen III reactors!