



Severe Accident Mitigation in Modern Nuclear Power Plants

**Brian Turland, John Lillington and Neil Harman,
Serco Technical Consulting Services, UK**

Presentation to

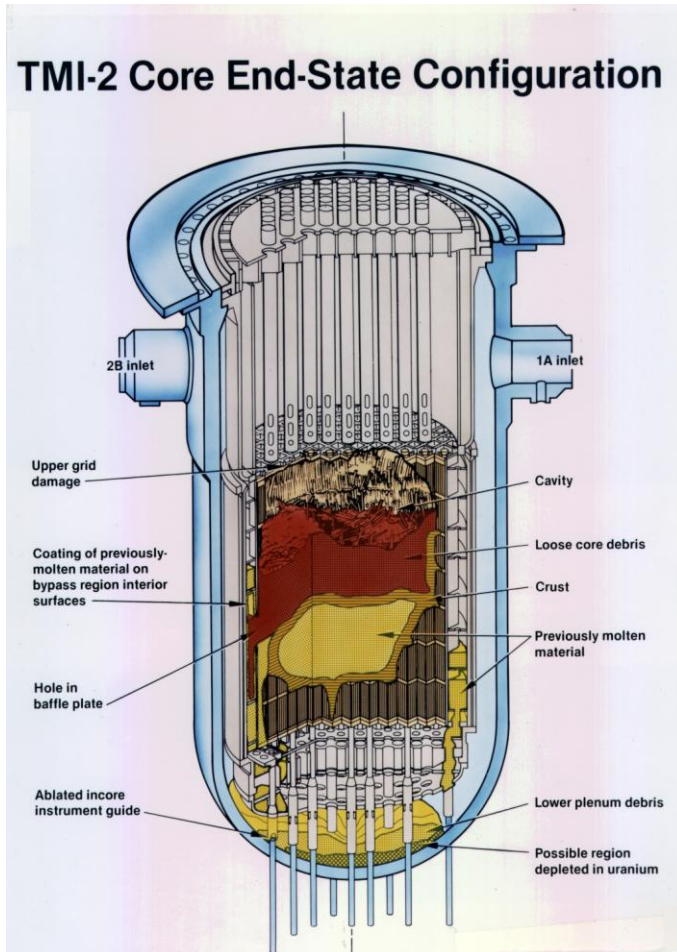
**The First Arab Conference on the Prospects of Nuclear Power for
Electricity Generation and Seawater Desalination, June 23 – 25, 2010**

Sizewell B Dome Image (right) courtesy of British Energy Group plc

Overview of Presentation

- Why provide provision against Severe Accidents?
 - The concept of “Defence-in-Depth”
- IAEA, Regulatory and Utility Requirements
 - The background to the provisions in New Build Designs
- Threats from Severe Accidents
 - What is being designed against
- Development of Severe Accident Management Strategies
 - The approaches available
- Overview of New Build Solutions
 - EPR, AP1000, ESBWR, ACR-1000
- Conclusions

Why provide provision against Severe Accidents?



- Generation II plants designed conservatively against “design basis accidents”
- This did not prevent the core-melt accident at TMI-2 in 1979
- However, there were sufficient barriers to the release of activity at TMI-2 to prevent a major release
- Impetus to further **prevent** severe accidents and **mitigate** consequences by understanding, and where necessary improving barriers to major release
- Application of probabilistic safety assessment to complement design basis analysis – benefits demonstrated in Sizewell B design (UK)

TMI-2 end-state image courtesy of USNRC

Defence-in-Depth

From IAEA – Safety of Nuclear Power Plants: Design (NS-R-1, 2000)

- To provide greater protection against a range of transients and accidents
- Level 1: Meet deviations in normal operation
- Level 2: Detect and intercept deviations from normal operation to prevent escalation into accidents
- Level 3: Defence against unlikely events in the design basis
 - Requirements for engineered safety features
- Level 4: Address severe accidents in which design basis may be exceeded
- Level 5: Mitigate consequences of potential releases
 - Plans for on-site and off-site emergency response

Defence-in-Depth: Level 4

Aim is to ensure that radioactive releases are kept as low as practicable.

- Most important objective is the protection of the containment function
- Can be achieved by:
 - Procedures (and additional provisions) to prevent accident progression
 - Mitigation of the consequences
 - Development of accident management procedures (guidelines)
- Protection can be demonstrated by “best estimate means”
 - Rather than conservative engineering approach for the engineered safety features
 - Consider full capability of the design

IAEA, Regulatory and Utility Requirements

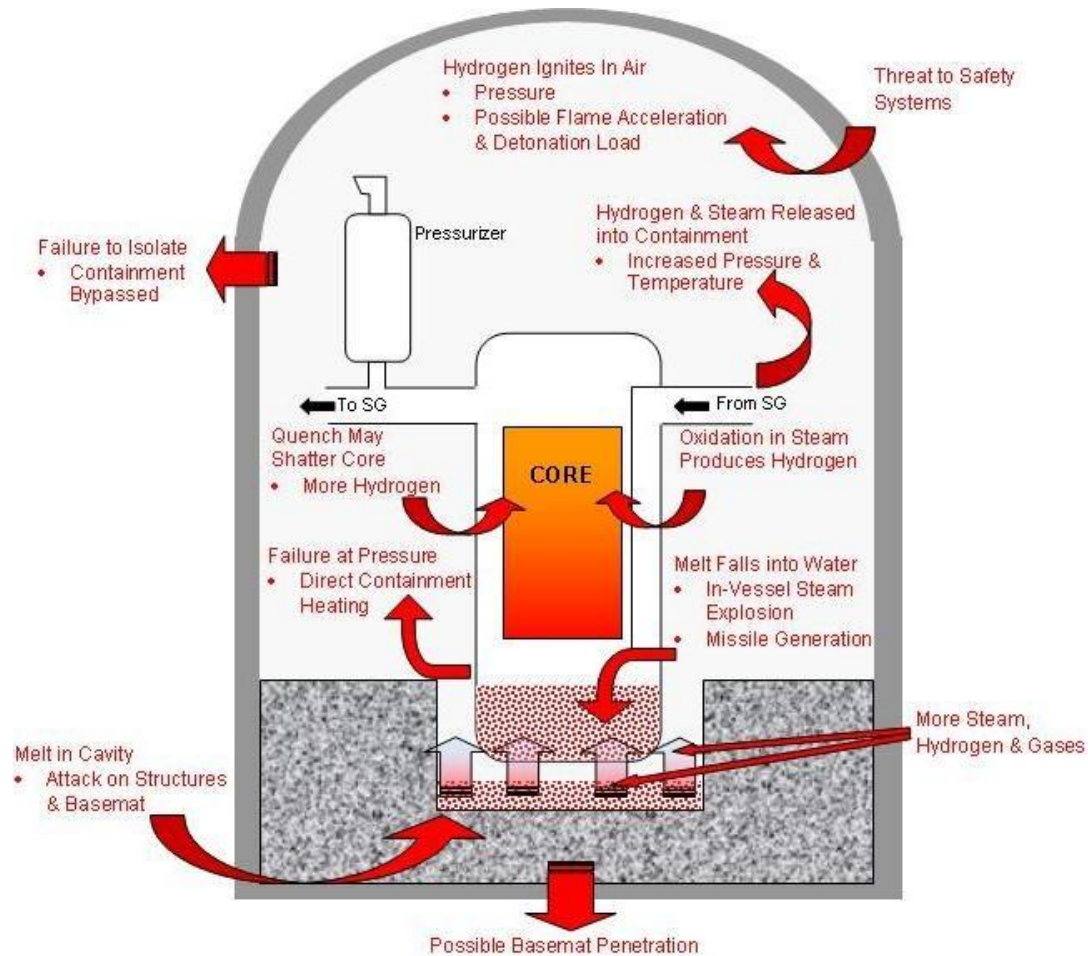
- In general Regulatory Requirements implement IAEA Standards
 - Approach for severe accident provisions currently differs between regulators (issue for New Build certification)
- Utility Requirements documents (e.g. EUR) specify
 - Core damage frequency less than 10^{-5} per reactor year
 - Large early release frequency less than 10^{-6} per reactor year
 - Design measures to mitigate severe accidents
 - ▶ Target is to reduce the likelihood of the need to off-site measures in response to an accident to a very low level
- IAEA and Regulator Expectations
 - Generally agree with target frequencies (which are typically an order of lower for Generation II plants).
 - IAEA Technical Documents on Severe Accident Management

UK Regulatory Expectations

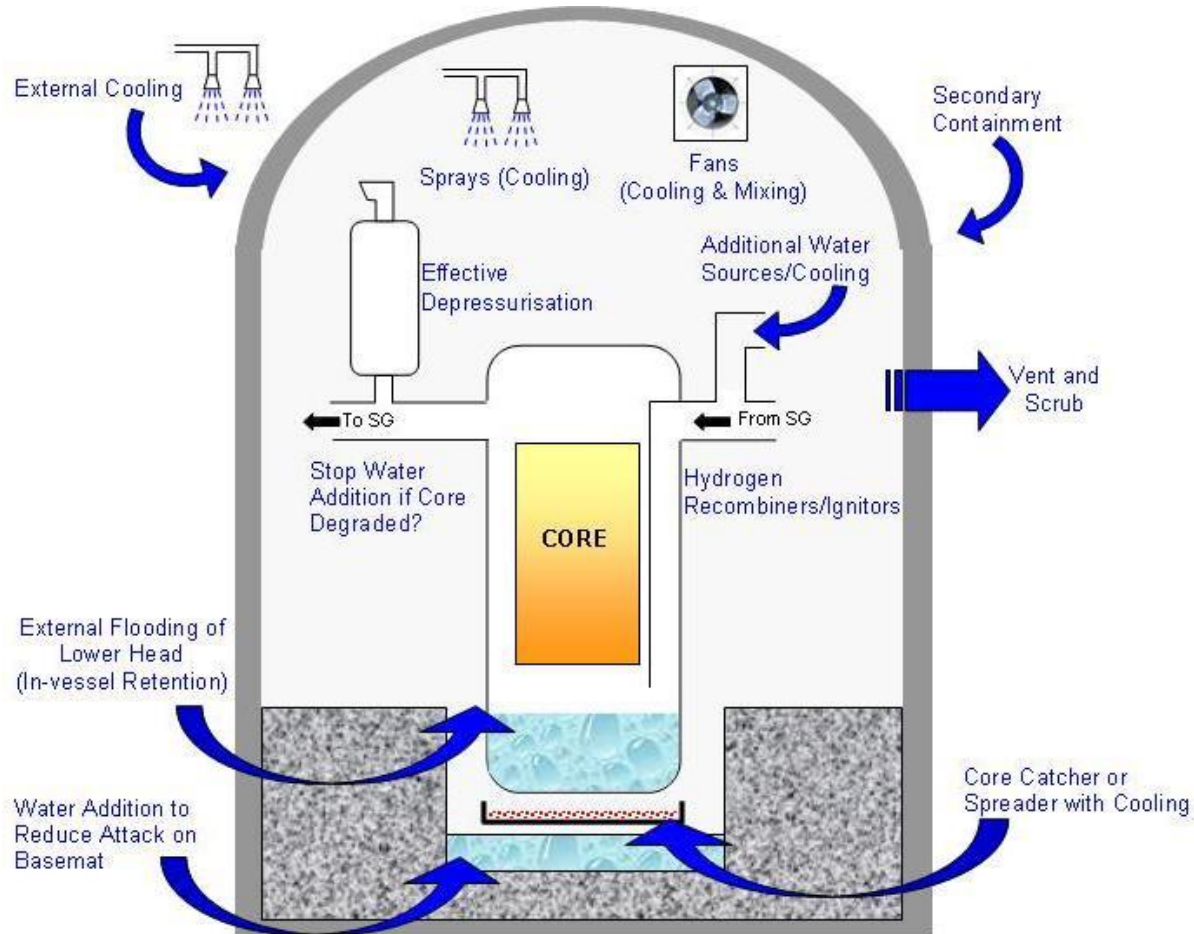
The UK Regulator is currently performing a Generic Design Assessment of two of the New Build Designs (EPR and AP1000)

- The UK system for safety assessment is not-prescriptive (licensee can choose approach and methods to demonstrate safety of plant).
- However, guidance issued of what is expected ([www.hse.gov.uk/nuclear/...](http://www.hse.gov.uk/nuclear/))
 - Safety Assessment Principles (SAPs)
 - Technical Assessment Guides
- Includes severe accidents as part of a comprehensive hazard identification and fault analysis process
 - Includes numerical targets, but requirement is to **demonstrate that the design is ALARP** – the risks are as low as is reasonably practicable (also no cliff-edges)
 - Use of best estimate methods for severe accident analysis supported

Threats from Severe Accidents



Mitigation Approaches



Development of Severe Accident Management Approaches

- Need to consider both positive and negative aspects of any course of action
 - Informed by international research programmes (some examples in paper)
 - Consider robustness of solutions to remaining uncertainties (e.g. in melt chemistry and melt-water interactions)
- Approaches may be issue-specific
 - Some issues (e.g. steam explosions) largely addressed by experimental programmes leading to improved understanding of the phenomena and quantification to demonstrate low likelihood of a significant threat
 - Other issues (e.g. direct containment heating) largely addressed by accident management provision (reliable depressurisation systems supported by accident management procedures and guidance)
 - Prevention of basemat erosion – may be addressed by water addition (existing plants), in-vessel retention or external core catcher (New Build)

SA mitigation in New Build candidate designs

■ Philosophy

■ EPR

- EURs, French and German regulators and utilities requirements
- Prevent high pressure core melt accidents
- Vessel failure at low pressure is not excluded; and so ex-vessel cooling is accommodated
- If failure occurs, the philosophy is to halt progression of the melt after spreading in the reactor vault
- Aim is to protect containment integrity for low pressure accidents

■ AP1000

- US URD, USNRC requirements
- Philosophy is to keep the melt debris inside the vessel
- Keep containment intact throughout accident
- Retaining molten corium inside the vessel prevents corium/concrete interaction and ex-vessel steam explosions from challenging the containment.

■ Design features

- Depressurisation system to prevent high pressure severe accidents
- A core retention system below the vessel has been developed (ex-vessel core-catcher with passive cooling system)
- The debris is then cooled by an overlying water pool with water supplied from the IRWST.
- The core catcher system is designed to prevent core-concrete interaction.
- Systems to control containment integrity and radionuclide releases (hydrogen management, sprays, filtration systems)
- Early core depressurisation in case of severe accident scenarios
- Ex-vessel cooling system
- Remove decay heat via passive containment cooling system
- Containment integrity control systems (hydrogen management etc)

SA mitigation in New Build candidate designs (Cont.)

■ Philosophy

■ ESBWR

- US URD, USNRC requirements
- Depressurisation and natural circulation lowers core melt frequency
- But there are design provisions if this is unsuccessful to catch and promote cooling of debris ex-vessel
- Protect containment integrity

■ ACR-1000

- CANDU design, CNSC requirements
- The technical basis for severe accident mitigation is in part derived from the LWR technical basis
- Optimisation of many passive safety features in existing CANDUs
- Maintain containment integrity

■ Design features

- The lower drywell floor has sufficient floor space to promote debris spreading, and also allows the inclusion for a Basemat-Internal Melt Arrest and Coolability (BiMAC) device to be considered to protect the containment liner and basemat.
- By flooding the lower drywell after the introduction of core material, the potential for energetic fuel/coolant interaction is minimised.
- Diverse active and passive heat removal systems to mitigate core damage consequences
- Passive containment systems, including hydrogen recombiners and igniters, sprays and containment heat removal systems

Conclusions – I

- Following the accident at TMI-2, the nuclear power industry
 - Took measures to reduce the likelihood of core melt accidents in the future
 - Looked at capability of existing plants to mitigate the radiological effects
- Based on
 - Application and development of probabilistic safety studies
 - Greater understanding of severe accident phenomenology (research)
 - Identification of Plant Vulnerabilities
 - Development and Application of “Defence-in-Depth” philosophy
- Requirements for New Build
 - Lower core melt frequency (by ~ an order of magnitude)
 - Lower frequency of early radiological release
 - Design measures to mitigate severe accidents (utility requirement)

Conclusions II

■ New Build Designs

- All have considered severe accidents as part of the design process
- Adopted different solutions
 - ▶ All have enhanced protection against core-melt
 - ▶ Solutions with retention in-vessel and ex-vessel
 - ▶ Preference for passive systems

■ Conclusion

- The nuclear power industry has learned the lessons of the past and is now able to offer New Build designs with an enhanced safety provision against a wider range of accident scenarios – providing enhanced safety.