Conceptual Design of Underground Toroidal Containment Extension Building for Increased Containment Integrity and Natural Decontamination Capability of Radioactive Materials during Nuclear Severe Accident Mitigation

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Presenter: Seong Woo Kang
Advisor: Man-Sung Yim

KAIST Korea Advanced Institute of Science and Technology

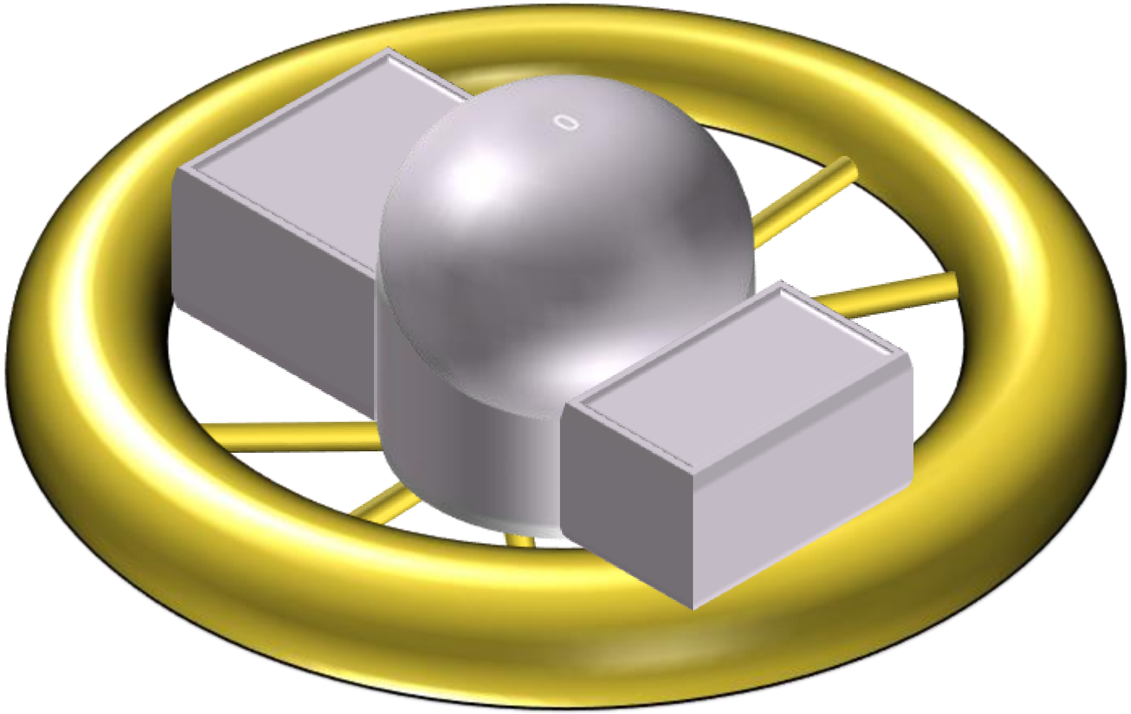
NENS Nuclear Energy Environment and Nuclear Security Laboratory

Purpose and Objective

- Research purpose:
  - To apply passive accident mitigation systems to improve safety of the nuclear power plant (NPP) in case of when loss of both AC and DC power occurs along with unavailability of other off-site power sources

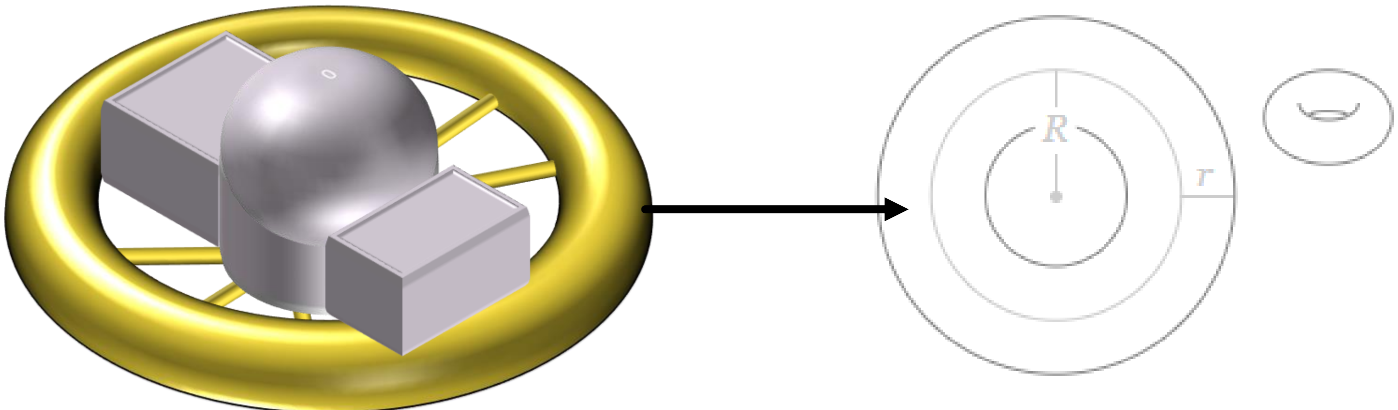
- Objective:
  - To introduce a containment building extension as an underground toroidal structure to further improve the NPP safety by enhancing its capabilities to withstand beyond design basis accidents

Concept of the Design



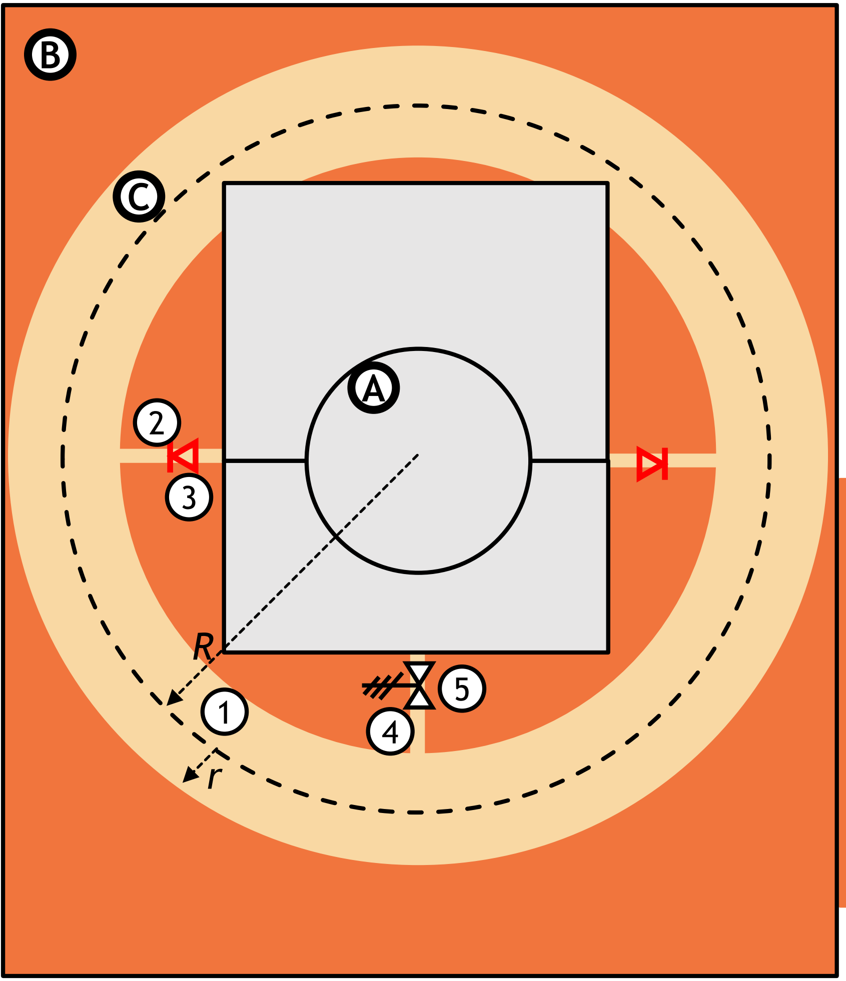
Concept of the design: to provide additional toroidal volume and thus extension of the containment survival time even during unforeseen severe accident scenarios with loss of AC and DC power in order to prevent the damage to the containment building

Quick Look at the Concept

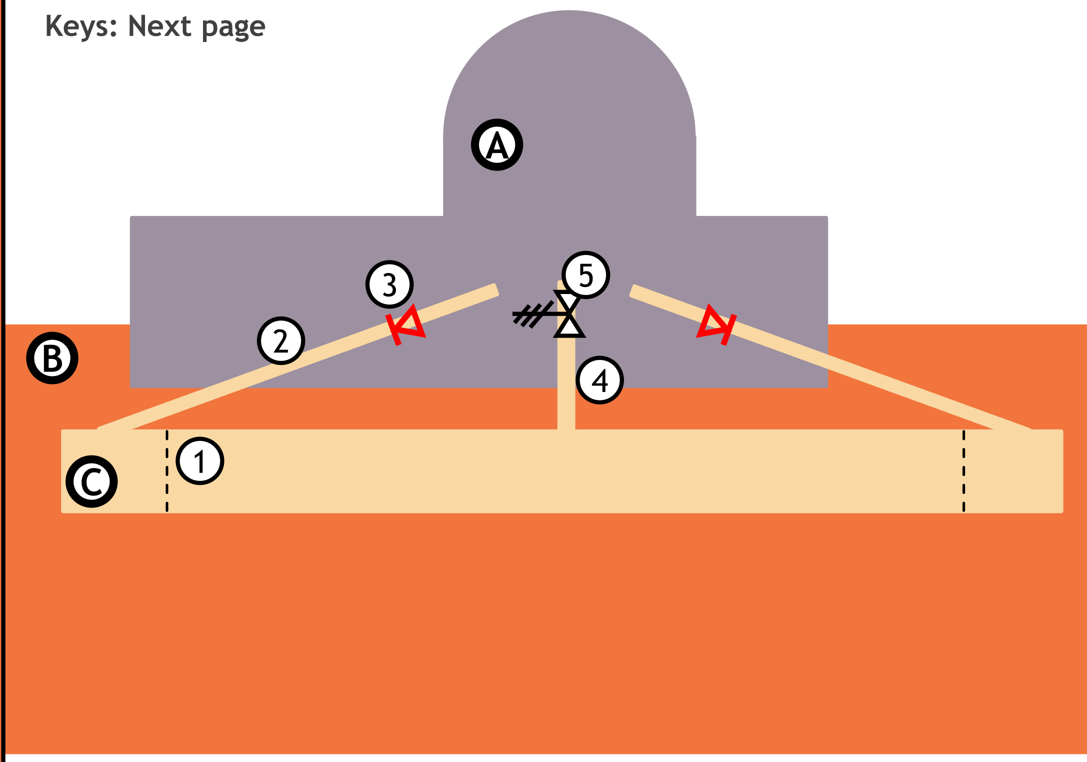


- Toroidal containment extension building has
  - Radius of revolution, ***R***, representing horizontal distance from center of the containment building
  - Radius of the circular section of the toroid, ***r***
- Underground placement allows the structure to be sturdier against pressure increases
- If *R* = 90m and *r* = 20m, the toroidal extension building can have roughly 10 times the free volume of the containment
  - As a reference, OPR-1000 has height and inner diameter of 66.8m and 43.9m, respectively (gray, stationed above ground)
  - If it can be constructed to have *r* = 25m, then horizontal distance *R* can be decreased to 60m and can still have over 10 times the free volume of the containment

Conceptual Design of the Toroidal Structure



Keys: Next page



<Top View>

<Side View>

Keys for the Conceptual Design

A. **NPP containment and auxiliary building**
B. **NPP site**
C. **Underground passive severe accident mitigation toroidal building for preventing containment integrity and for natural decontamination of radioactive materials (patented KR10-2202856)**
   1. Underground Toroidal building
      - Reasoning behind torus shape: sturdier against over-pressurization when the structure is closer to the circular shape (instead of typical straight building)
      - To withhold short-lived radioactive materials within the structure for natural decontamination (iodine, xenon, etc.)
      - May have dry filters to adsorb iodine and cesium within the toroidal structure
      - For economic purposes, may be able to connect one underground toroidal structure to 2~4 nuclear reactor containment buildings
   2. Check valve lines
      - From the containment to the toroidal building and safety valve lines from the toroid to the containment
      - When pressure gradient occurs between the containment and the underground toroidal structure, allow flow of the radioactive materials passively

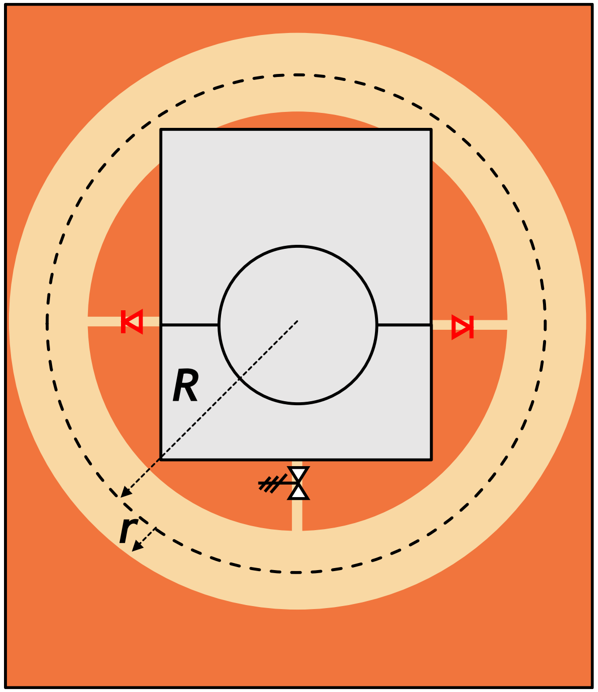
Keys for the Conceptual Design

c. **Underground passive severe accident mitigation toroidal building for preventing containment integrity and for natural decontamination of radioactive materials (patented KR10-2202856)**

3. Check valves
   - To prevent radioactive gases from having a backflow into the containment building
4. Relief valve lines
   - After natural decontamination and before getting into dangerous pressure level inside the toroidal building, allow opening of the manual relief valves to slowly release remaining long-lived radioactive gases for further decontamination during accident management
   - Amount of radioactive waste can be reduced by securing enough time to first filter the radioactive gases using dry filters before releasing through relief lines for further decontamination
5. Pilot operated relief valves
   - After most radioactive materials with short half-lives are decontaminated, to release manually in a controlled manner for further decontamination of cesium and remaning radioactive gas through filtration

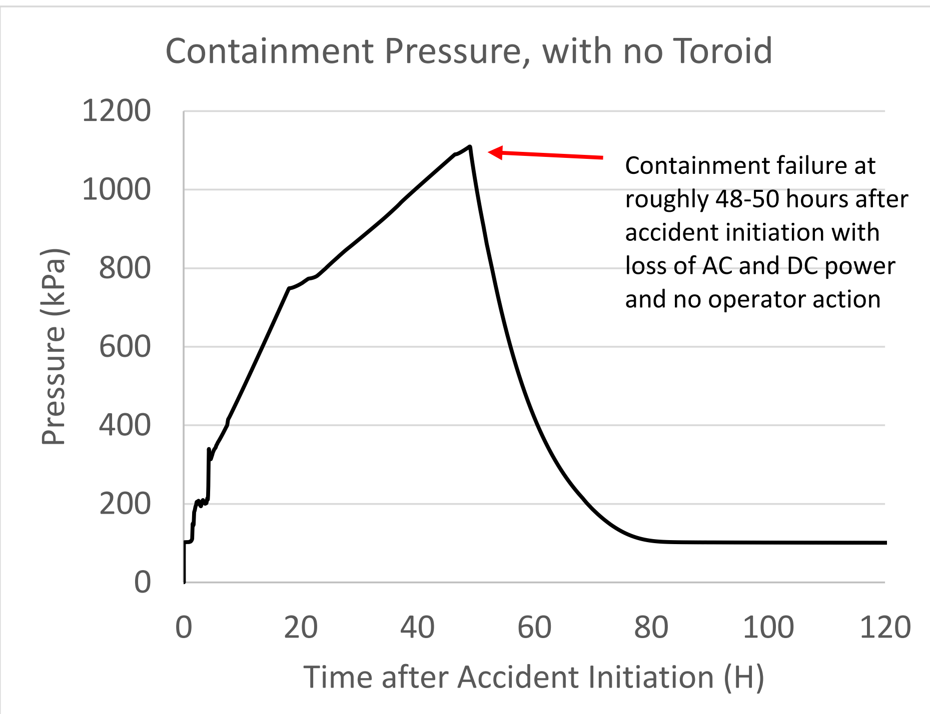
Simulation using Severe Accident Code

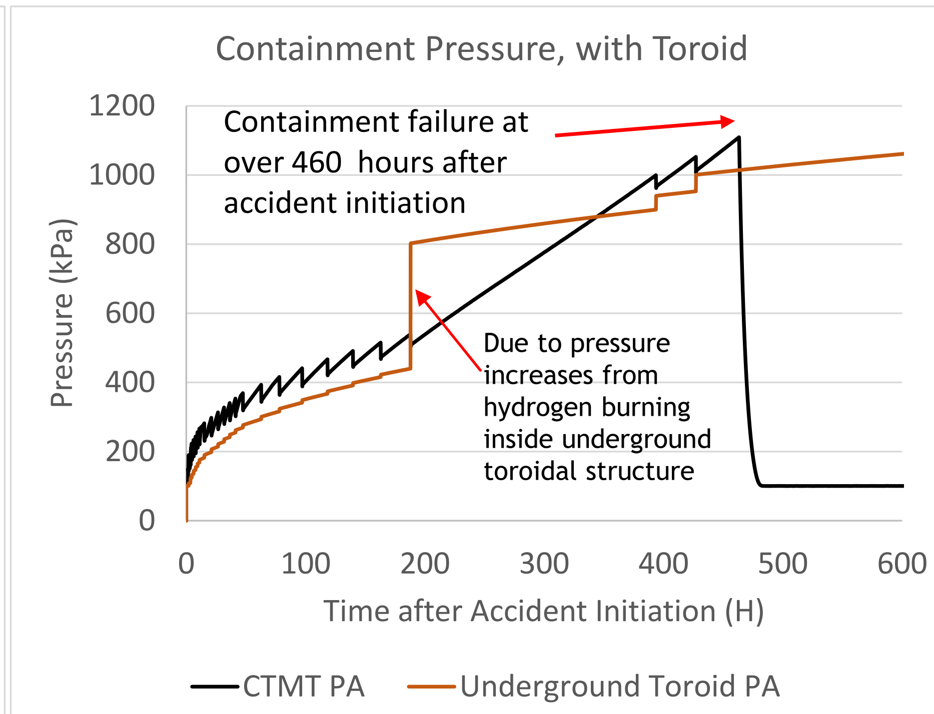
- Simulation for severe accident with loss of AC and DC powers, without and with underground toroidal extension
  - MAAP4 for severe accident simulation
    - *R* = 88.56m, *r* = 20m, at 30 m below the ground level
    - Check valve opens and closes if differential pressures between the containment and the toroid building are greater than 14.7 psi (~1 atm) and less than 5 psi, respectively
    - Aerosol sedimentation area inside the toroidal building assumed to occupy 1/3 of the total area
    - No passive autocatalytic recombiners (PARs) for conservative results
  - Accident scenario: unmitigated long-term station blackout accident (from State-of-the-Art Reactor Consequence Analysis)



Simulation Results

- No toroid: simulation results show that it would result in a containment failure in roughly 2~3 days from unmitigated station blackout accident, as expected from a typical 1000 MWe pressurized water reactor
- With toroid: with chosen design parameters (*R* = 88.65m, *r* = 20m), much more time for accident response may be secured before the containment fails (~460 hours from the simulation)
  - Additional time would allow short-lived radionuclides (such as I-131) to decay significantly inside the toroidal structure





<Containment pressure during unmitigated long-term station blackout accident, without and with underground toroid extension>

Summary and Future Work

- The underground toroidal containment extension building as proposed in the study may result in the improvement in the NPP severe accident mitigation capability through providing much larger additional volume and thus extension of the containment survival time
    - Additional response time provided should allow better onsite and offsite responses
- To reduce the costs, it is also possible to build one toroidal structure underground with connections to multiple reactor buildings at a site, so that any one of the connected reactor buildings can use the toroidal structure in case of a severe accident with containment over-pressurization
- Additional research is required to further show the feasibility of this technology
    - More extensive structural analysis should be performed
    - Limitations of the soil/rock conditions to use underground toroidal structure should also be defined
    - More detailed analysis of the impacts of additional safety systems (e.g. PAR, radioactive iodine/cesium filters, cooling system, etc.) inside the toroid should be performed, as these may impact its capability of holding the radioactive gas inside
    - Technoeconomic analysis should also be performed to better predict the cost of using this structure