APR1000 Major Components Design and EUR Assessment

Materials / Components for NSSS

May. 17, 2023
DOOSAN ENERBILITY Nuclear Business Group
PARK GUNWOO

Table of Contents

1. Introduction

Who we are

- Doosan Enerbility is one of the global leading companies in equipment manufacturing for nuclear power plant.

History

- 1962 Established
- 1981 Acquired ASME certificates
- 1987 Selected as the main contractor for Hanbit 3&4
- 2006 Received order for the 1st APR1400, Shin-kori 3&4
- 2007 Received order for 2 units of AP1000 from China
- 2008 Received order for 6 units of AP1000 from U.S
- 2010 Received order for 4 units of APR1400 from UAE
- 2011 Received order for 2 units of APR1400, Shin-hanul 1&2
- 2014 Received order for 2 units of APR1400, Shin-kori 5&6

2. MATERIAL-RELATED REQUIREMENTS (Ch. 2.06)

Prohibited Materials for RCS Components (Cobalt based Alloy)

- EUR Requirement Ch. 2.06 Material related requirements
- Ch. 2.06 compliance assesment result of NOC
  - ✓ Section 2.6.4.1.2 Requirements for materials in contact with the reactor coolant
  - ✓ Section 2.6.4.1.2 Requirement A.G,

Revision E *December, 2016*

Section	*Requirement*	*Nuclear/Turbine/Common*	*Section comment*	*Last change*
A.G	• the cobalt content of all materials in contact with the reactor coolant, including systems connected to the RCS, shall be minimised to avoid activation in the core radiation field of entrained corrosion products which could lead to the production of cobalt 60: ○ high-cobalt alloys such as stellites shall not be used for valve seat hard-facing materials in systems in contact with reactor coolant. Cobalt-free hard-facing alloys currently developed and proven shall be used. The Designer* shall assess possible alternatives and shall provide justification of the chosen solution; ○ cobalt-based materials shall not be used in Reactor Vessel* internals; and ○ specifications of the maximum cobalt present as impurity in materials shall be proposed by the Designer* for all internal surfaces of the RCS. For Steam Generator* (SG) tubing, the maximum tube bundle average cobalt content should be limited to 150 ppm. For Boiling Water Reactor (BWR) plant, the cobalt content in the main heat exchangers (main condenser and feed water heaters) should be limited to 200 ppm.	N	A.G1 Components with cobalt contents to improve material performance are permitted within the specified limits, provided their use is well-proven and no suitable alternative exists. A.G2 Significant improvements in the technology and maintenance of valves without hard-facing materials are also to be noted. A.G3 The intent of the EUR requirement is to avoid the use of cobalt-based alloys but permits some exceptions. The use of cobalt-based alloy may be permitted for some components, such as the Control Rod Drive Mechanism. A.G4 Strict values for cobalt contents are set in the EUR to meet the required reduction in operational radiation exposure, as well as other requirements such as SG tube integrity, and extra costs, according to the state of technology. See Chapter 2.6 Section 2.6.3.5	

2. MATERIAL-RELATED REQUIREMENTS (Ch. 2.06)

- **Prohibited Materials for RCS Components (Cobalt based Alloy)**

Requirements	Assessment result
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Cobalt-free hard-facing alloys currently developed and proven shall be used.	**NOC**
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shall provide justification of the chosen solution;	COM

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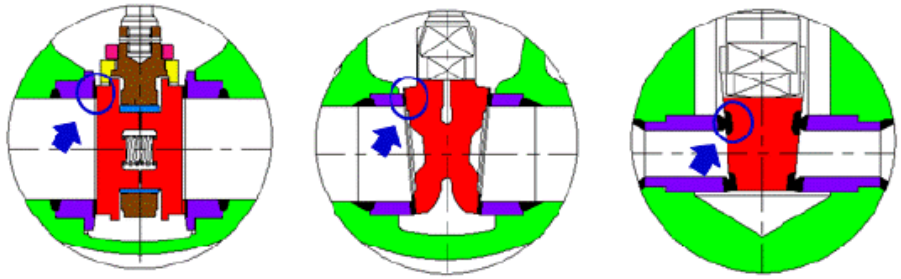
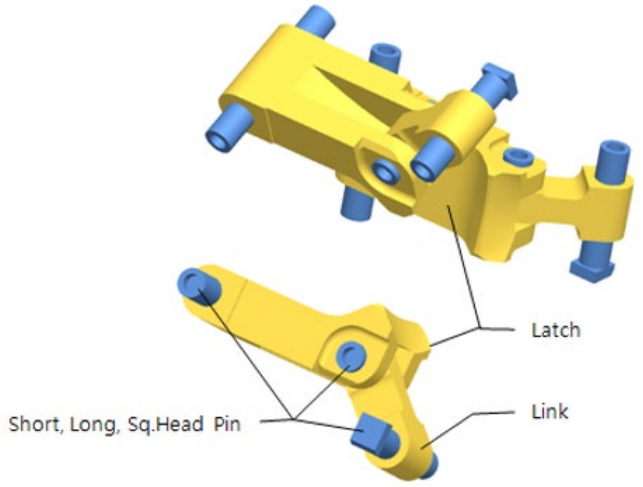
2. MATERIAL-RELATED REQUIREMENTS (Ch. 2.06)

- **Advantages of cobalt based alloy**
  - Low friction coefficient and wear resistance
  - Guaranteed functioning under high temperature & environmental impact

- **Cobalt based alloy in APR1000**
  - Seat area of Valve
  - Latch, Link & Pin for CEDM (Control Element Drive Mechanism)



Valve seat hardfacing area

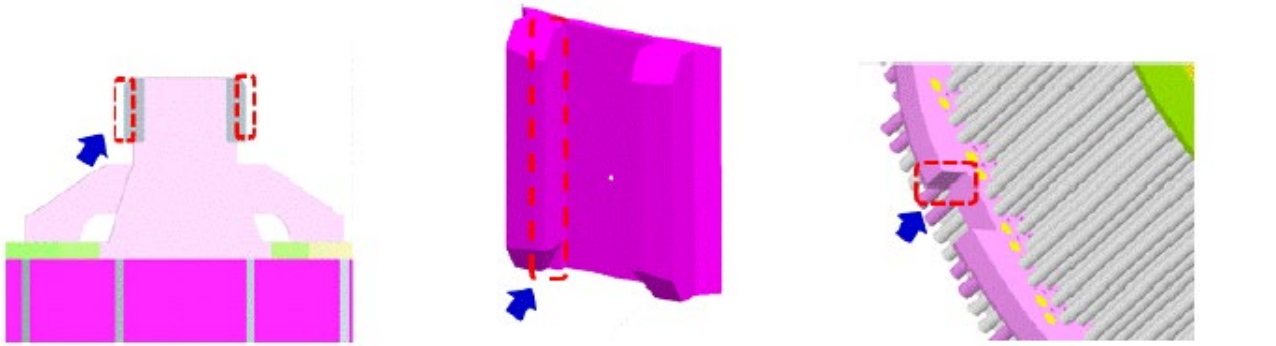


Control Element Drive Mechanism Latch / Link /Pin

2. MATERIAL-RELATED REQUIREMENTS (Ch. 2.06)

- **Cobalt based alloy in APR1000 (Cont'd)**
  - Hard facing area for RVI (Reactor Vessel Internal)
    - ✓ Core Support Guide Lug Insert, Core Support Snubber Lug, Fuel Alignment Plate key slot
- **Technical Understanding**
  - Hard facing area : very small and limited area of the entire RVI surface area
  - **<u>Cobalt based alloys in EUR satisfy ORE (Occupational Radiation Exposure) criteria</u>**

    (Very small portion of the component, and Radiation exposure to worker is negligible.)



Core Support Guide Lug Insert | Core Support Snubber Lug | Fuel Alignment Plate Key Slot

<u>Reactor Vessel Internal</u>

3. Steam Generator Design Development (Ch. 2.07)

Background of Steam Generator Design Development

- EUR Requirement Ch. 2.07 FUNCTIONAL REQUIREMENTS: Components
  - ✓ Section 2.7 Requirements for Steam Generators

2.7 2.7.4 Size

A	A heat-transfer area with sufficient margin shall be provided to allow for fouling and plugging.	N

- Top Tier Requirement for APR1000
  - ✓ Section 6. Main Features of NSSS and BOP

6.1.3.2 10% tube plugging margin

Rationale

- Successful experience from operating NPPs shall be reflected in the APR1000 design.
- The SGs are designed for the specified conditions of reactor coolant flow and temperature to produce the specified steam mass flow rate and pressure at full power. The margin of 10% of the total heat transfer surface area for the plugging is provided in the SGs to assure the capability to produce the specified steam mass flow and pressure at full power.

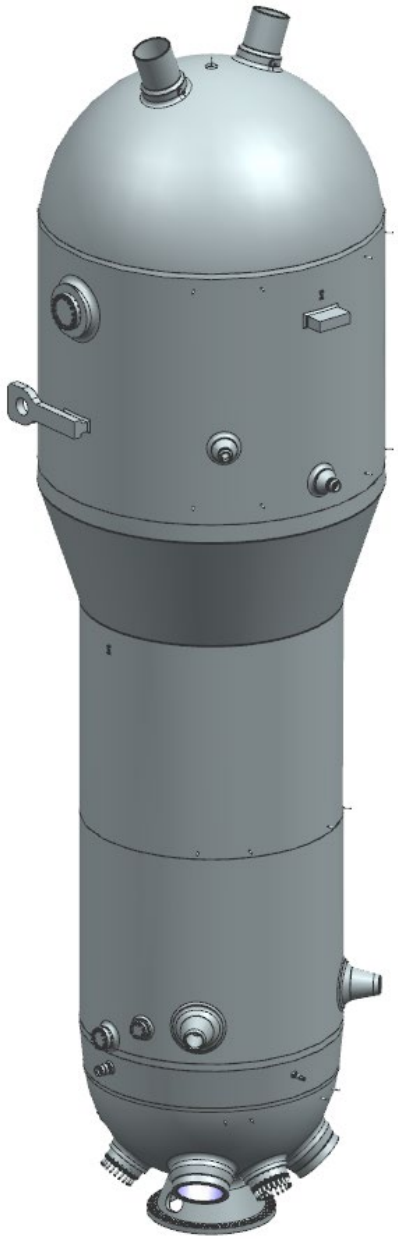
3. Steam Generator Design Development (Ch. 2.07)

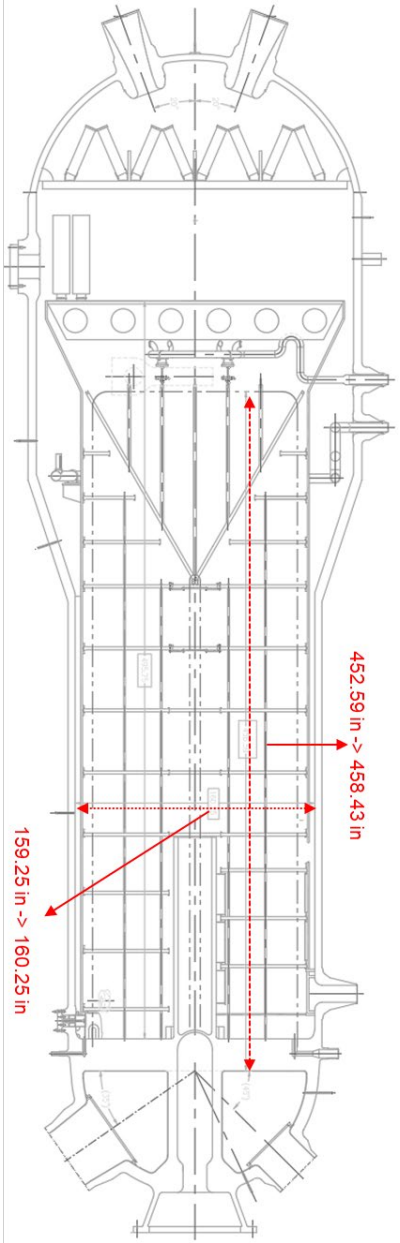
Development status of steam generator design

- Summary of major design changes
  - ✓ Heat transfer area is expanded to satisfy design thermal output by applying 10% tube plugging rate
  - ✓ In order to expand the heat transfer area, increasing the number of heat transfer tubes and the length of heat transfer tube

	OPR1000	APR1000
Total number of heat transfer tubes	8340 EA	8471 EA (+ 131)
Average of heat transfer tubes length	65.79 ft	66.39 ft (+ 0.6 ft)
Tube plugging rate	8%	10%
Outside diameter of Steam generator	159.25 in	160.25 in (+ 1 in)

3. Steam Generator Design Development (Ch. 2.07)

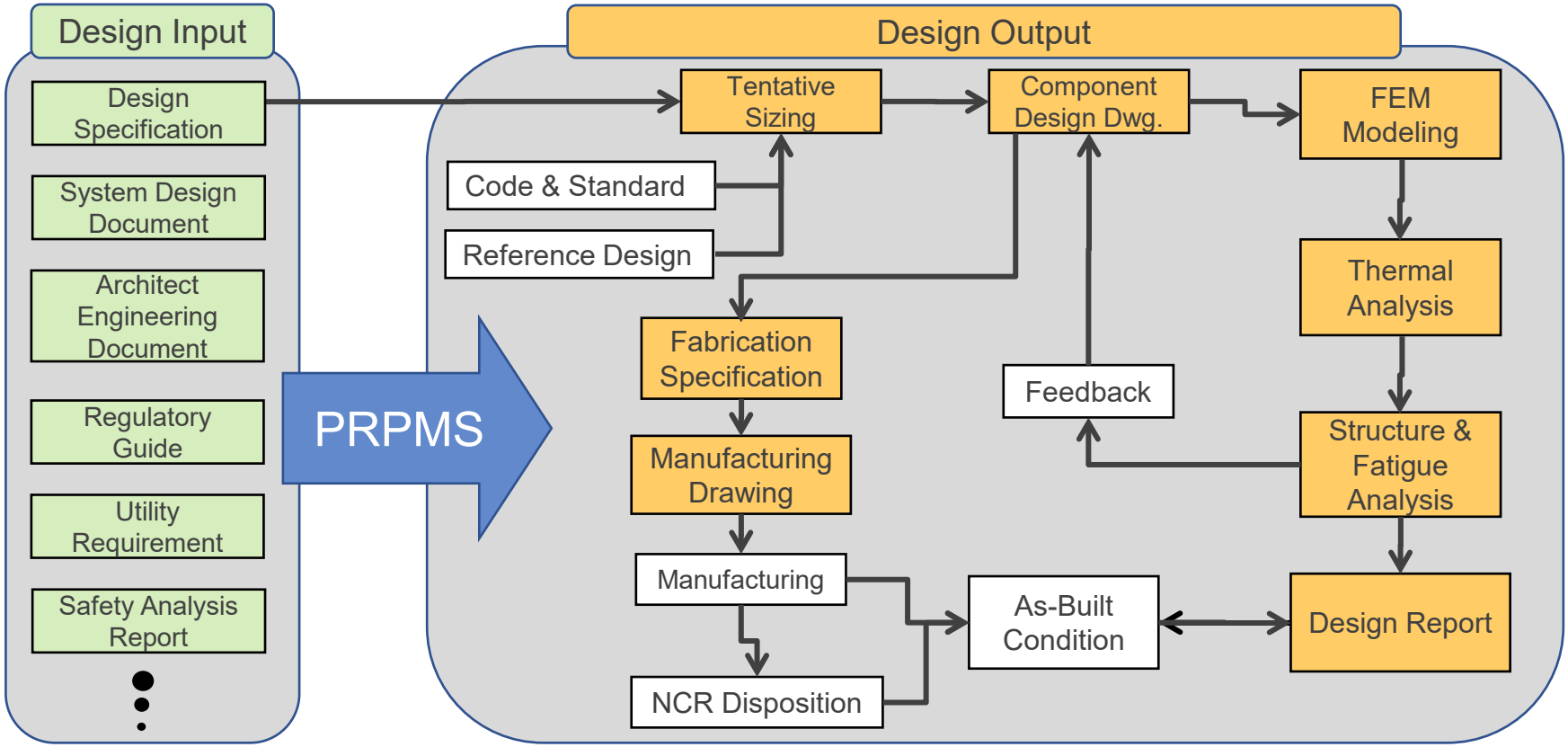




4. Design and Manufacturing Component

Component Design Process

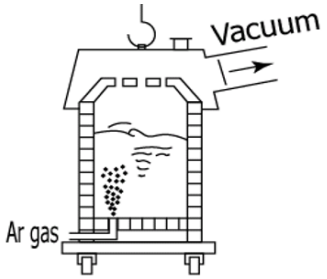
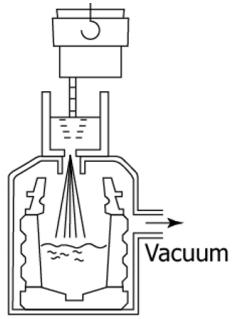
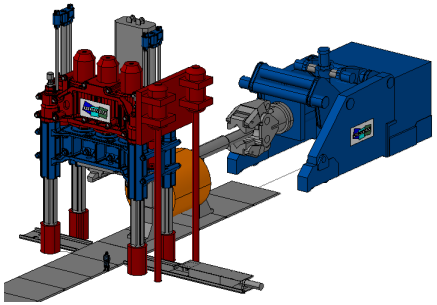
- Typical design process according to quality assurance system
- Control of precedence(upstream) requirements via PRPMS*



*PRPMS : Precedence Requirements Pass-down Management System

4. Design and Manufacturing Component

Forged Material

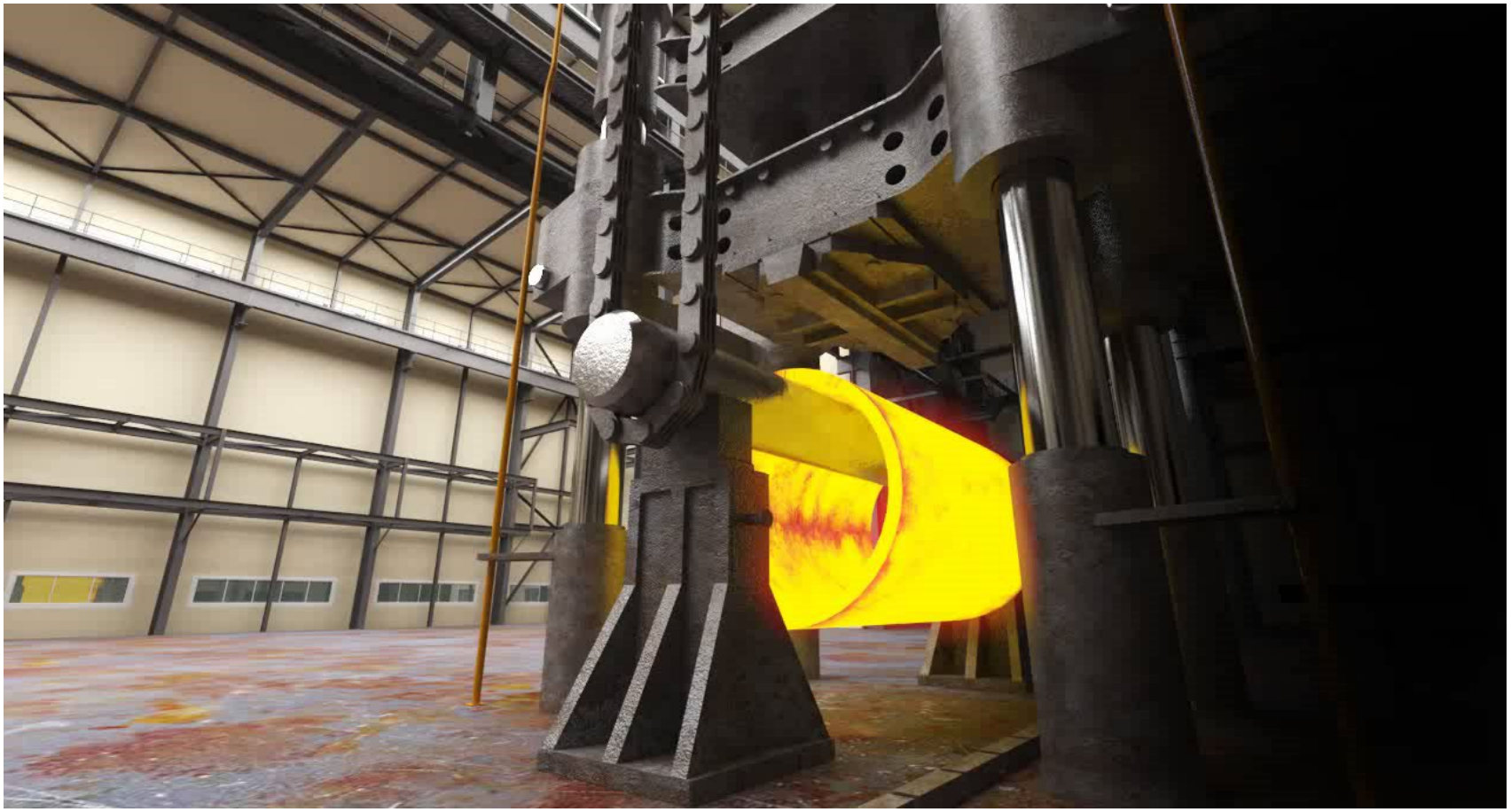
Process	Feature	Remarks
Ladle Refining		Ladle Refining Furnace - Equipped with vacuum cover - Argon gas is bubbled - Induction stirrer are used - Degassing in vacuum condition - Non-metallic inclusion floatation
Pouring & Ingot Making		Mold located in vacuum chamber - Degassing in vacuum condition - Removing non-metallic inclusions (Oxides, Sulfides, Nitrides)
Forging		17,000 ton Press & Manipulator - Φ7,500 mm Shell - Φ7,650 mm Disk

4. Design and Manufacturing Component

- **Forged Material**

4. Design and Manufacturing Component

- **Forged Material**



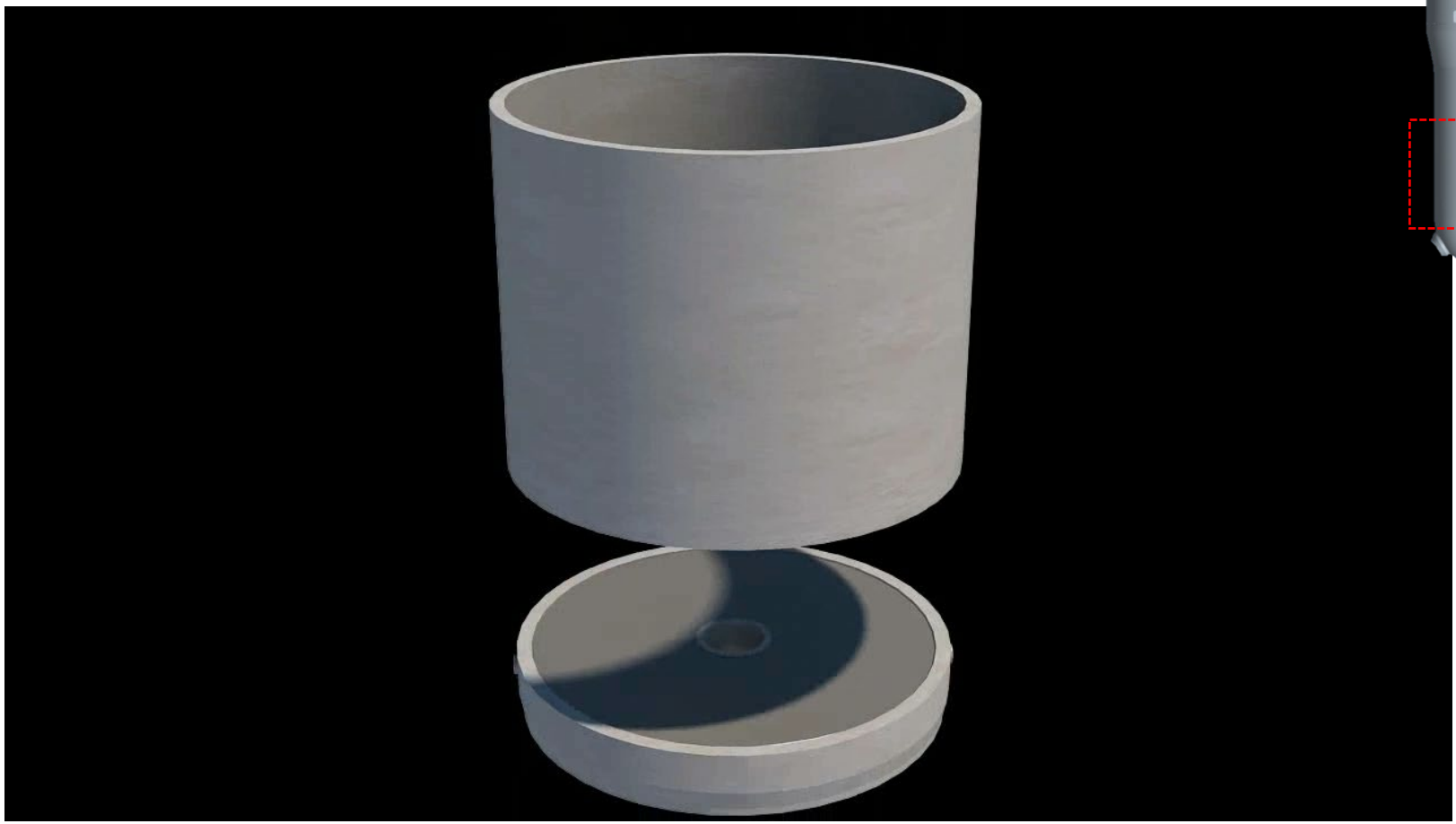
4. Design and Manufacturing Component

Steam Generator

- Tubesheet cladding

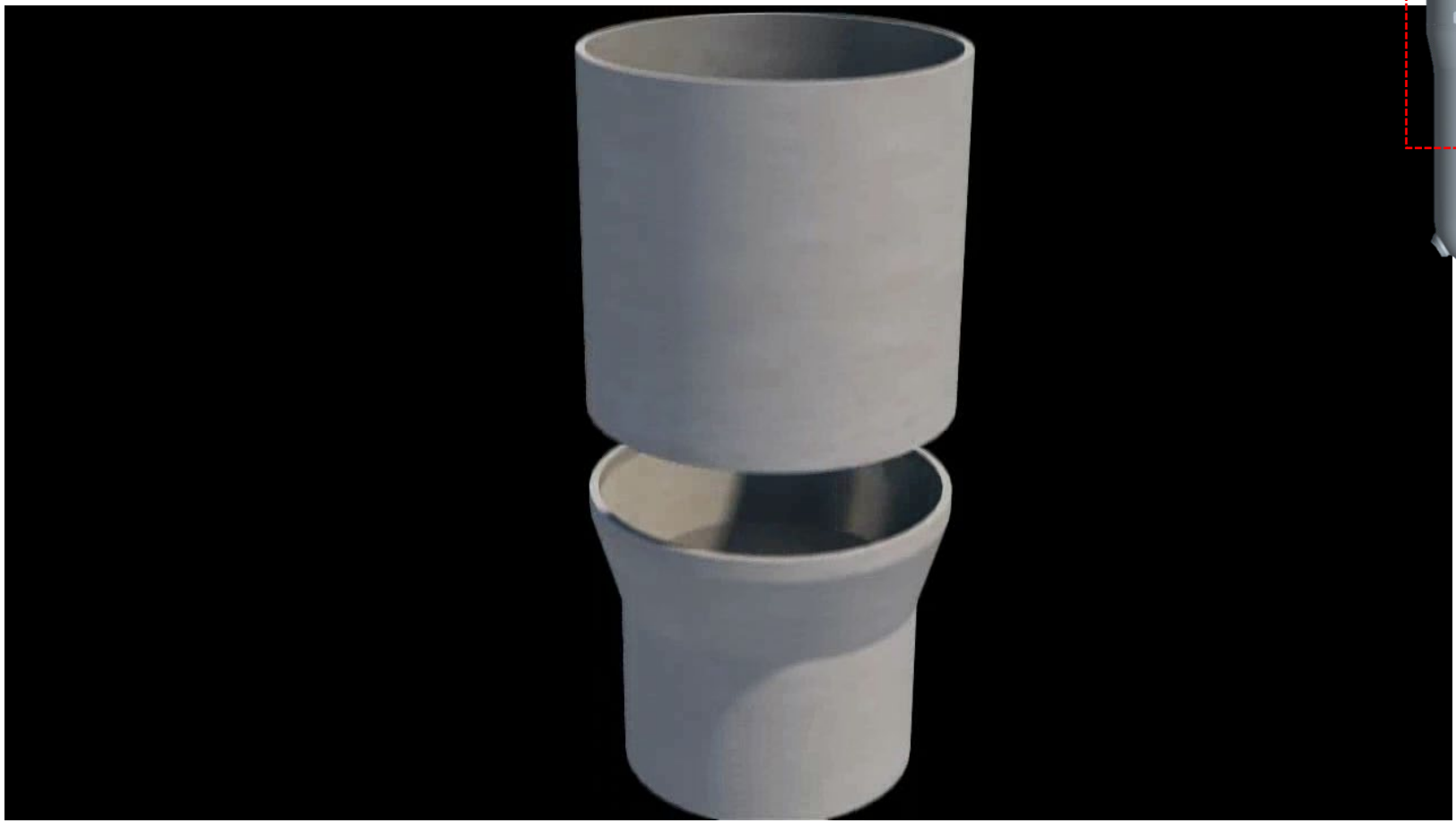
4. Design and Manufacturing Component

- **Steam Generator**
  - Lower vessel assembly



4. Design and Manufacturing Component

- **Steam Generator**
  - Upper vessel assembly completion



4. Design and Manufacturing Component

- **Steam Generator**
  - Lower to upper vessel assembly

4. Design and Manufacturing Component

- **Steam Generator**
  - Installation of internals - Tube shroud to envelop internals

4. Design and Manufacturing Component

- **Steam Generator**
  - Installation of internals - Eggcrate to support heat transfer tubes

4. Design and Manufacturing Component

Steam Generator

- Installation of internals - Tubing, welding to tubesheet and expansion

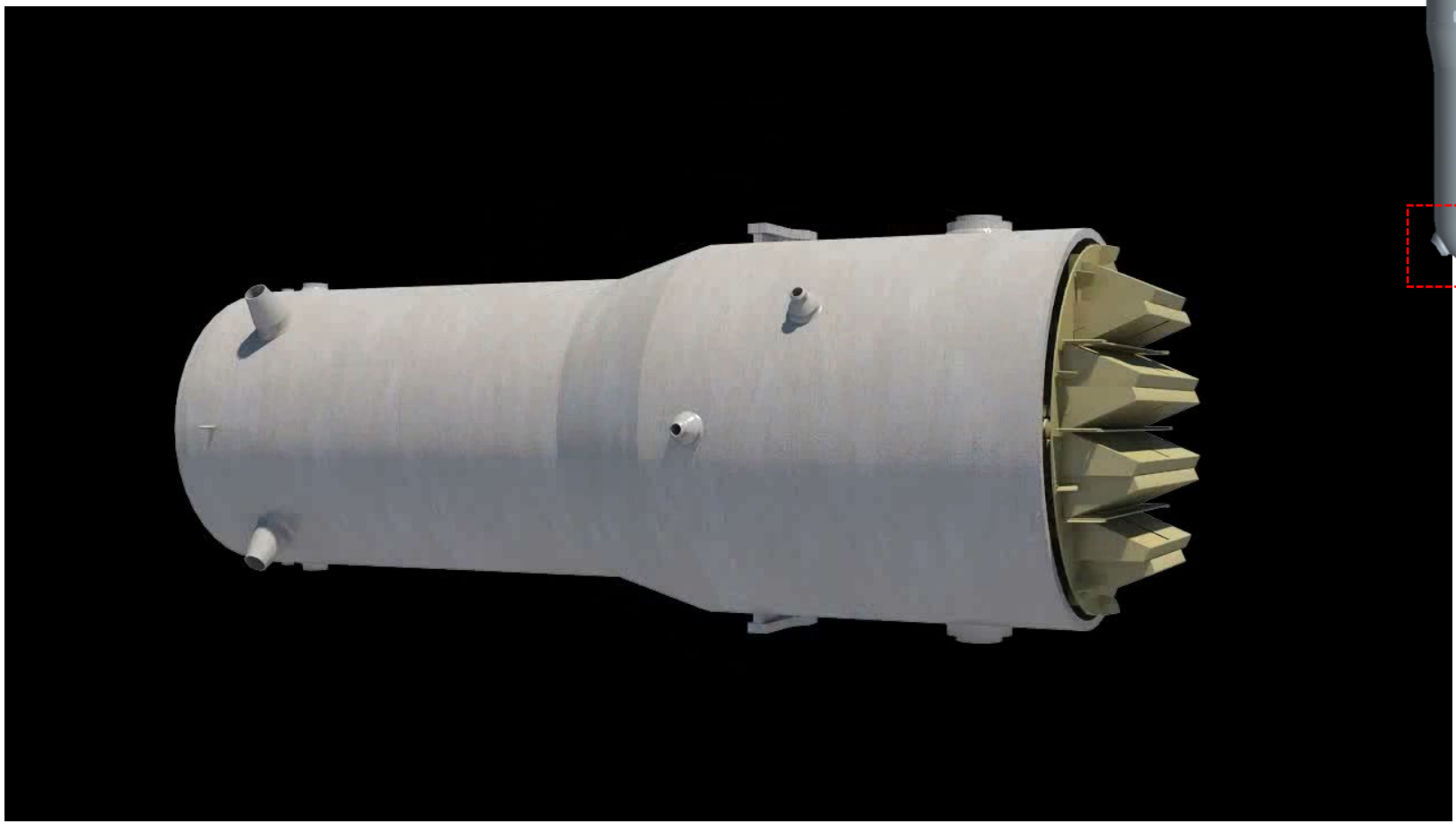
4. Design and Manufacturing Component

Steam Generator

- Installation of internals - Tube support beam, moisture separator and steam dryer, etc.

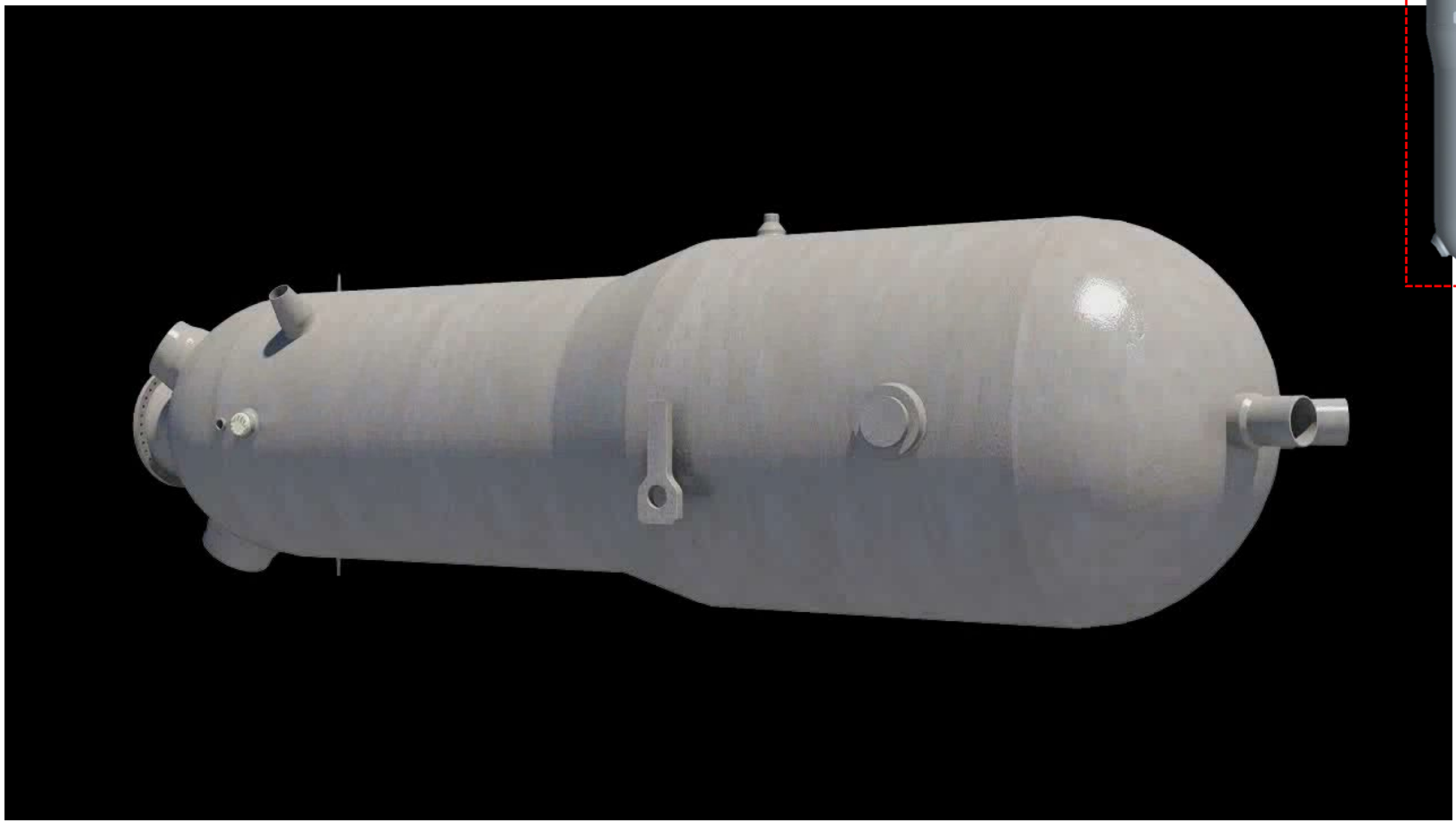
4. Design and Manufacturing Component

- **Steam Generator**
  - Secondary Head & Primary Head Welding



4. Design and Manufacturing Component

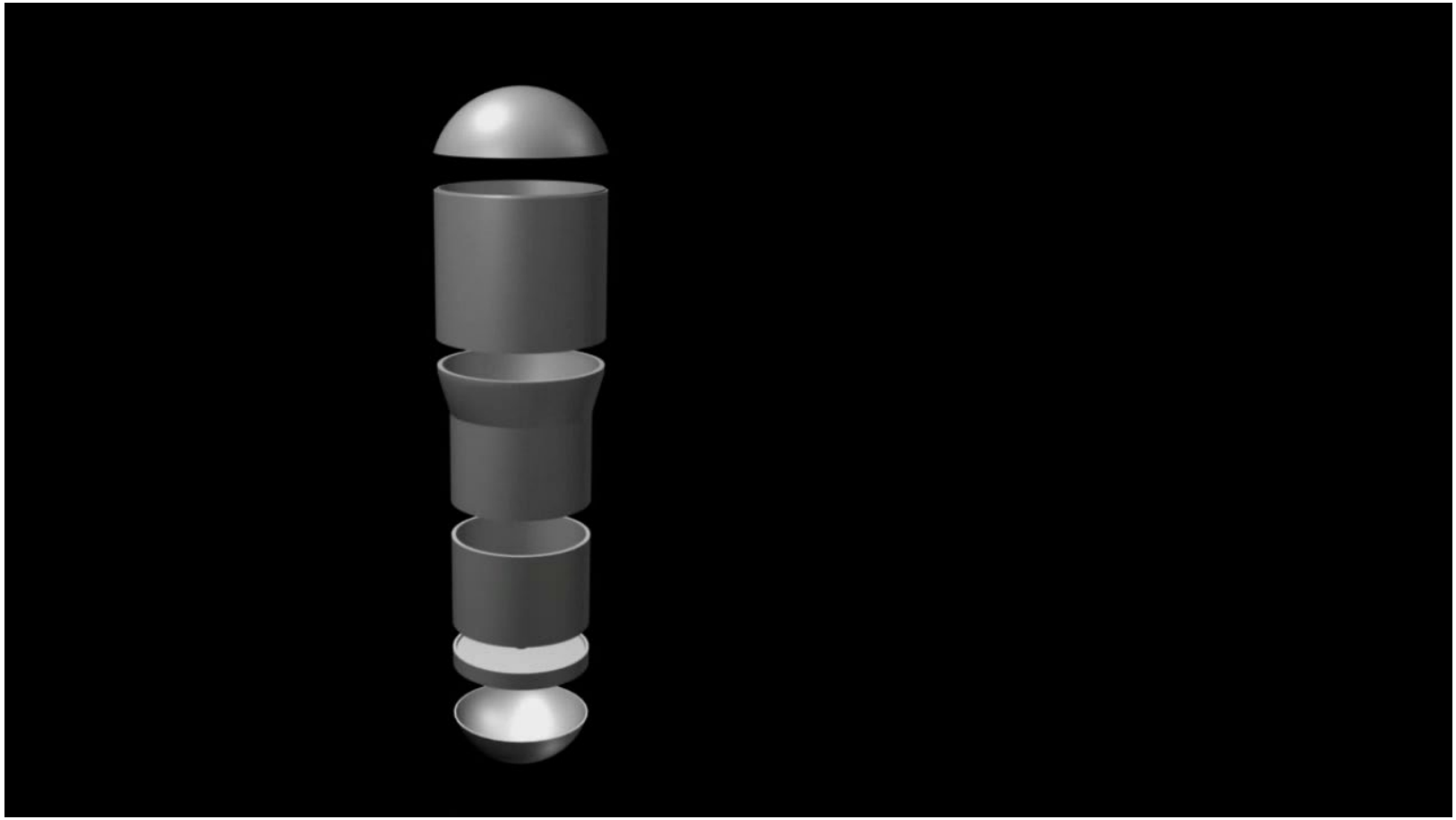
- **Steam Generator**
  - Hydrostatic Test



4. Design and Manufacturing Component

Steam Generator

- Manufacturing process at a glance



4. Summary & Suggestion

Summary

- As a NSSS equipment supplier, Doosan mainly supported Ch. 2.06 and 2.07.
- NOC was issued because of using cobalt based material in contact with reactor coolant, but APR1000 satisfies ORE requirement.
- On going development to satisfy 10% heat transfer tube plugging margin rate of APR1000 steam generator

Lessens & Learned

- It is opportunity to realize the Europe strongly requires the use of proven cobalt-free materials.
- It is necessary for Korea to make preparation to prove cobalt-free materials in terms of NPP safety by promoting development tasks such as verification tests at NPP.

Thank You