Reactor Internals Design

Faculty of Mechanical Engineering
Ljubljana University (May 30, 2019)

Korea Atomic Energy Research Institute

Kyeong-Hoon Jeong
Hydro Electric Power Plant in My Home Town

Chilbo Hydroelectric Power Plant
Constructed in 1945, Net Capacity: 30MWe
3% of Korean Standard Nuclear Power Plant Single Unit
2% of Korea APR1400 Single Unit
Korean Commercial Nuclear Power Plants in Operation

<table>
<thead>
<tr>
<th>Reactor</th>
<th>Type</th>
<th>Net capacity</th>
<th>Supplier</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kori 1, 2</td>
<td>PWR</td>
<td>563 MWe 612 MWe</td>
<td>Westinghouse (USA)</td>
<td>4/78 ~ 6/17 7/83</td>
</tr>
</tbody>
</table>

Kori Unit 2 is a sister plant of Krško nuclear power plant in Slovenia. This plant is more advanced plant than Kori Unit 2 nevertheless its operation on Jan. 1983.

<table>
<thead>
<tr>
<th>Reactor</th>
<th>Type</th>
<th>Net capacity</th>
<th>Supplier</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wolsung 1</td>
<td>PHWR (CANDU)</td>
<td>629 MWe</td>
<td>AECL (Canada)</td>
<td>4/83, Shutdown for Estimation of Life Extension</td>
</tr>
<tr>
<td>Wolsung 1</td>
<td>PWR</td>
<td>903 MWe</td>
<td>Westinghouse (USA)</td>
<td>9/85, 4/86</td>
</tr>
<tr>
<td>Hanbit 1, 2</td>
<td>PWR</td>
<td>900 MWe</td>
<td>Westinghouse (USA)</td>
<td>8/86, 6/87</td>
</tr>
<tr>
<td>Hanul 1, 2</td>
<td>PWR</td>
<td>920 MWe</td>
<td>Framtome (France)</td>
<td>9/88, 9/89</td>
</tr>
<tr>
<td>Hanbit 3, 4</td>
<td>PWR (OPR)</td>
<td>950 MWe</td>
<td>Hanjung, KAERI (Korea) CE (USA)</td>
<td>12/95, 3/96</td>
</tr>
<tr>
<td>Wolsung 2, 3, 4</td>
<td>PHWR (CANDU)</td>
<td>650 MWe</td>
<td>Hanjung (Korea) AECL (Canada)</td>
<td>6/97, 6/98, 6/99</td>
</tr>
<tr>
<td>Hanul 3, 4, 5, 6</td>
<td>PWR (OPR)</td>
<td>960 MWe</td>
<td>Hanjung, KOPEC, KAERI (Korea)</td>
<td>6/98, 6/99, 1/04, 12/04</td>
</tr>
<tr>
<td>Hanbit 5, 6</td>
<td>PWR (OPR)</td>
<td>950 MWe</td>
<td>Doosan, KOPEC (Korea)</td>
<td>5/02, 12/02</td>
</tr>
<tr>
<td>Shin Kori 1,2</td>
<td>PWR (OPR)</td>
<td>950 MWe</td>
<td>Doosan, KOPEC (Korea)</td>
<td>2/11, 3/12</td>
</tr>
</tbody>
</table>
## Korean Nuclear Power Plants under Construction or on Order

<table>
<thead>
<tr>
<th>Reactor</th>
<th>Type</th>
<th>Net capacity</th>
<th>Start-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shin Wolsung 1, 2</td>
<td>PWR (OPR)</td>
<td>950 MWe</td>
<td>3/12, 1/13</td>
</tr>
<tr>
<td>Shin Kori 3, 4</td>
<td>PWR (APR)</td>
<td>1350 MWe</td>
<td>3/16, 9/18</td>
</tr>
<tr>
<td>Shin Hanul 1, 2</td>
<td>PWR (APR)</td>
<td>1350 MWe</td>
<td>Under Test</td>
</tr>
<tr>
<td>Shin Kori 5, 6</td>
<td>PWR (APR)</td>
<td>1350 MWe</td>
<td>Under Construction</td>
</tr>
<tr>
<td>Shin Hanul 3, 4</td>
<td>PWR (APR)</td>
<td>1350 MWe</td>
<td>Suspended</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>(24 plants in operation)</strong></td>
<td><strong>22,500 MWe</strong></td>
<td><strong>17.5% in Total Electric Power Production (2018)</strong></td>
</tr>
</tbody>
</table>
Nuclear Power Plant

Reactor Types

- PWR: Pressurized Water Reactor
- BWR: Boiled Water Reactor
- PHWR (CANDU): Pressurized Heavy Water Reactor
- Graphite Moderated Reactor (PBMR)
CANDU Reactor

- Natural uranium (0.7% U-235 + 99.3% U-238)
- Zirconium alloy cladding
- Heavy water (D₂O) moderator
Nuclear Steam Supply System (2-Loop System)

- WH-type
- Krško NPP
Nuclear Steam Supply System (3-Loop System)
Nuclear Steam Supply System (4-Loop System)

- Manufacturing Cost
- Transportation
- Structural Integrity of Reactor Vessel
Nuclear Steam Supply System (CE Type)

- Nozzle /Fuel Location
- ICI Locations
- Hot Leg & Cold Leg Change??
Main Components of NSSS

Steam Generator

Reactor
Manufacturing of Reactor Pressure Vessel

- Key for Operating Life Extension of NPP
  - Krško NNP (40+10+10)
  - Exchange MCP & SG, PZR, Closer Header
  - Degradation of RV by Increase of Brittleness due to Irradiation, Impurity Control
  - Surveillance Program – Charpy Specimens

- What does NPP capacity decide?
  - Manufacturing Equipment for Forging, Heat Treatment, Handling
  - Transportation and Handling in Construction Site
Main Components of NSSS

Pressurizer

Reactor Coolant Pump

Pressurizer:
- SPRAY NOZZLE
- SAFETY NOZZLE
- MANWAY
- UPPER HEAD
- INSTRUMENTATION NOZZLE
- LIFTING TRUNION (LOAN BASIS)
- SHELL
- LOWER HEAD
- INSTRUMENTATION NOZZLE
- ELECTRICAL HEATER
- SUPPORT SKIRT
- SURGE NOZZLE

Reactor Coolant Pump:
- FLYWHEEL
- UPPER RADIAL BEARING
- THRUST BEARING
- MOTOR SHAFT
- MOTOR STATOR
- MAIN LEAD CONDUIT BOX
- LOWER RADIAL BEARING
- NO. 3 SEAL LEAK OFF
- NO. 2 SEAL LEAK OFF
- PUMP SHAFT
- COOLANT WATER INLET
- DISCHARGE NOZZLE
- SUCTION NOZZLE
- THRUST BEARING OIL LIFT PUMP + MOTOR
- MOTOR UNIT ASSEMBLY 
- SEAL HOUSING
- NO. 1 SEAL LEAK OFF
- MAIN FLANGE
- COOLING WATER OUTLET
- RADIAL BEARING ASSEMBLY
- THERMAL BARRIER AND HEAT EXCHANGER
- CASING
- IMPELLER
Reactor Vessel Assembly and Fuel Assembly

- Natural Uranium
  - (Approximate 4%~5% U-235 + U-238)

- 300°C Tem.
- 15 MPa Press.

- Initial Heating ?
- Why 300°C ?
- Why 15 MPa ?
Westinghouse Reactor Vessel Assembly and Fuel Assembly
Comparison of Fuel Assembly

CE Type

WH Type

16
Fuel Assembly and Control Element Assembly
Control Element Assembly of CE Type
Arrangement of Control Element Assembly in Core (1)
Arrangement of Control Rod Assembly in Core (2)
Reactor Internals
Westinghouse Reactor (Krško NPP) & Other Reactor

WH Type  

CE Type (APR1400)  

SMART
Core Support Barrel Assembly

Components: Core Support Barrel
Core Shroud
Lower Support Structure
Alignment Keys

Major Functions
1. Provide a support structure for the core.
2. Provide a suitable coolant pass.
3. Provide a shield for reactor vessel against irradiation damage.
4. Align the core and guide in-core instrumentation

Material: 304 Stainless Steel
Upper Guide Structure Assembly

Components:
- Top Hat (Guide Structure Support System)
- Control Element Assembly Shroud
- UGS Barrel
- Fuel Alignment Plate
- Hold Down Ring
- UGS Support Plate

Major Functions
1. Protect the control elements from coolant flow.
2. Maintain the core in lateral and azimuthal alignment.
3. Limit the lifting of the core.
4. Support and guide control elements.
Alignment Key

- Interface Alignment Key to Reactor Vessel Head
- Upper Guide Structure
- Hold Down Ring
- Dowel Pin
- Core Support Barrel
Reactor Pressure Vessel

Material: SA508 Gr.3 Cl. 1 + S.S. Cladding
(Flow Skirt: Alloy 690)
Reactor Vessel Closure Head

- Closure Head Nozzle
- Head Lift Rig Pad
- Stud Hole
- Mating Surface
- O Ring Groove
- Guide Funnel
- Key Way

Reactor Vessel Closure Head
Refueling Pool Arrangement

CSB Storage Stands

UGS Storage Stands
Upper Guide Structure Lift Rig Assembly
Core Support Barrel Lift Rig
Upper Guide Structure Storage Stands

UGS LIFT RIG MOUNT

UPPER GUIDE STRUCTURE(UGS) STORAGE STAND
Core Support Barrel Storage Stands
Core Support Barrel Shipping Skid
Upper Guide Structure Shipping Skid
Installation of Reactor Internals

Installation of UGS Assembly

Installation of CSB Assembly
Preparation of Design Documents

- Mechanical Engineering Scope of Engineering
  → Define Scope of Engineering, Work Products, Contracts
- System Description
  → Describe Configuration and Functions
- System Design Requirements
  → Summarize Design Requirements, Classify the components
- Design Specification
  → Functional Requirements, Performance Requirements,
    Define Design Loads, Interface Loads, …
- Fabrication Specification
  → Requirement for Material, Manufacturing, Welding, Cleaning
- Design Reports ( = Stress Reports)
  → Stress Calculation, Fatigue Analysis, Tolerance Study
- Installation Guidelines
- Operation Guidelines
Design of Reactor Internal Structures (2)

- Preparation of Design Calculation and Analysis
  - Initial Sketches – General arrangement, Determination of thickness of major component
  - Initial Sizing Calculation
    → Define Scope of Engineering, Work Products, Contracts
  - Preparing Detailed Drawings
  - Input to Safety Analysis – Surface Area, Mass, Material, Coolant Flow Area, Coolant Peripheral Distance
  - Analysis Modeling
    → Describe Configuration and Functions
  - Stress Calculations (Design by Formula)
    → Summarize Design Requirements, Classify Components by Regulation
  - Deformation Calculation
    → Insertability Check of Control Rods during SSE
What is the Design?

- A preliminary sketch or outline showing the main features of something to be executed.
- Everything except Fabrication and Operation
Manufacturing Process

- Design: Understanding of All Process → Comprehensive, Predictive, Economic, Time Saving
Major Concerns for Good Design

- **Purposiveness**: Regulation (Law, Code and Standards), Requirements from Purchaser.

- **Economy**: Expanse in Design Manufacturing and Transportation, Design Life.

- **Creativeness**: Avoidance Infringement of Patent

- **Maintenance**: Inspection, Repair, Cost for Maintenance, Standard Item

- **Convenience**: User and Operator Friendly.

- **Fabrication**: Simple Structure, Manufacturing Method, Fixing Method, Material Delivery, Fabrication Tools and Machines

- **Transportability**: Size, Weight, Transport Vehicle, Installation Machine

- **Beauty**: Color, Shape, Appearance (Negligible)
Knowledge for Mechanical Design

- **Material**: Physical and Mechanical Properties, Chemical Properties, Metallurgical Property, Price


- **Engineering**: Electromagnetics, Control and Instrument, Kinematics

- **Manufacturing**: Mechanical Drawing, Manufacturing Tools and Methods, Inspections after Welding

- **Software**: FEM Codes (ANSYS, Abacus, PATRAN, ..), Mathematical Tools (MathCAD, Mathematica), 3-D Modeling Tools (I-DEAS, Solid Edge)

- **Regulations**: Law, Code & Standard (International & Domestic)
Analyses for Design

- Analysis Category
  - Stress Analysis → FEM (ANSYS, Abacus, )
  - Deformation Analysis → Insertability during SSE, Thermal Expansion
  - Coolant Flow Analysis
  - Thermal Analysis → Temperature Distribution & Mechanical Property Change by Temperature
  - Fatigue Analysis → Cumulative Usage Factor < 1
  - Electro-magnetic Analysis → Operation of CRDM
  - Static Analysis
  - Dynamic Analysis
    - Seismic Analysis, Postulated Pipe Break Analysis
    - Modal Analysis, Time History, Response Spectrum
  - Tolerance Study
  - Input for Safety Analysis
Design Requirements

- Functional Requirements
- Performance Requirements – Design Life
- Regulatory Requirements – Inspection, Classification
- Design Requirements – Design Loads, Allowable Criteria
- Installation Requirements
- Interface Requirements
- Operating Requirements
- Environmental Requirements
- QA Requirements
- Fabrication Requirements
- Material Requirements
- Shipping, Handling, Cleaning, Storage Requirements
- Test Requirements
- Identification Requirements
Codes and Standards (1)

- **ASME Boiler and Pressure Vessel Code**
  - ASME BPVC Section I - Rules for Construction of Power Boilers
  - ASME BPVC Section II - Materials
    - Part A - Ferrous Material Specifications
    - Part B - Nonferrous Material Specifications
    - Part C - Specifications for Welding Rods, Electrodes and Filler Metals
    - Part D - Properties (Customary)
    - Part D - Properties (Metric)
  - ASME BPVC Section III - Rules for Construction of Nuclear Facility Components
    - Subsection NCA - General Requirements for Div. 1 and Div. 2
  - Appendices
 Codes and Standards (2)

- **ASME Boiler and Pressure Vessel Code**
  - ASME BPVC Section III - Rules for Construction of Nuclear Facility Components
    - **Division 1**
      - Subsection NB - Class 1 Components
      - Subsection NC - Class 2 Components
      - Subsection ND - Class 3 Components
      - Subsection NE - Class MC Components
      - Subsection NF - Supports
      - Subsection NG - Core Support Structures
    - **Division 2** - Code for Concrete Containments
    - **Division 3** - Containment Systems for Transportation and Storage of Spent Nuclear Fuel and High-Level Radioactive Material
    - **Division 5** - High Temperature Reactors
Codes and Standards (3)

- Subsection NG - Core Support Structures
  - NG-1000 Introduction – Scope, Definition, Boundary of Jurisdiction
  - NG-3000 Design – Design by Rules, Design by Analysis, Design Criteria, Stress Limit, Design for Welded Construction
  - NG-4000 Fabrication and Installation – Certification of Material, Repair of Welding, Welding Qualification, Heat treatment, Mechanical Joints
  - NG-5000 Examination – Requirement of Examination of Weld, Permissible Examination Methods, Requirements for Radiography, Ultrasonic, Liquid Penetrant, Magnetic Particle Examination, Qualification and Certification for Nondestructive Personnel
  - NG-8000 Nameplate, Stamping, Reports
Codes and Standards (3)

- ASME Boiler and Pressure Vessel Code
  - ASME BPVC Section IV - Rules for Construction of Heating Boilers
  - ASME BPVC Section V - Nondestructive Examination
  - ASME BPVC Section VI - Recommended Rules for the Care and Operation of Heating Boilers
  - ASME BPVC Section VII - Recommended Guidelines for the Care of Power Boilers
  - ASME BPVC Section VIII - Rules for Construction of Pressure Vessels
  - ASME BPVC Section IX - Welding, Brazing, and Fusing Qualifications
  - ASME BPVC Section X - Fiber-Reinforced Plastic Pressure Vessels
  - ASME BPVC Section XI - Rules for Inservice Inspection of Nuclear Power Plant Components
  - ASME BPVC Section XII - Rules for the Construction and Continued Service of Transport Tanks
  - ASME BPVC Code Cases - Boilers and Pressure Vessels

- KOREA Code & Standard → KEPIC
Classification of Reactor Internals

- **Safety Class 3 → Safety Related**
  - Korea Notice of Nuclear Safety and Security Commission, Promulgation Number 2016-10, Regulations on Safety Classification and Applicable Codes and Standards for Nuclear Reactor Facilities

- **Seismic Category I**
  - USNRC Regulatory Guide 1.29, Seismic Design Classification.

- **CVAP Classification**
  - USNRC Regulatory Guide 1.20, Rev.04, Comprehensive Vibration Assessment Program for Reactor Internals during Preoperational and Initial Startup Testing
# Basic Stress Intensity Limit

<table>
<thead>
<tr>
<th>Stress Intensity</th>
<th>Tabulated Value</th>
<th>Yield Strength</th>
<th>Ultimate Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Primary Membrane (Pm)</td>
<td>Sm</td>
<td>≤ 2/3 Sy</td>
<td>≤ 1/3 Su</td>
</tr>
<tr>
<td>Local Primary Membrane (Pl)</td>
<td>1.5 Sm</td>
<td>≤ Sy</td>
<td>≤ 1/2 Su</td>
</tr>
<tr>
<td>Primary Membrane + Bending (Pm+Pb)</td>
<td>1.5 Sm</td>
<td>≤ Sy</td>
<td>≤ 1/2 Su</td>
</tr>
<tr>
<td>Primary + Secondary (Pl+Pb+Q)</td>
<td>3 Sm</td>
<td>≤ 2 Sy</td>
<td>≤ 1/2 Su</td>
</tr>
</tbody>
</table>
Stress Analysis Method

Elastic Analysis

Limit Analysis

Plastic Analysis
Design Stress Limit

Design Criteria by Limit Analysis

(Pm+Pb) / Sy

Collapse Stress

Design Limits

Design Criteria by Limit Analysis
Criteria of Stress Intensities for Service Levels A and B

**FIG. NG-3221-1** STRESS CATEGORIES AND LIMITS OF STRESS INTENSITIES FOR SERVICE LEVELS A AND B

<table>
<thead>
<tr>
<th>Stress Category</th>
<th>Primary Stresses</th>
<th>Secondary Stresses</th>
<th>Peak Stresses, F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane, $P_m$ [Notes (1), (2), and (3)]</td>
<td>$P_m$</td>
<td>$P_m + P_b$</td>
<td>$P_m + P_b + Q$</td>
</tr>
<tr>
<td>Bending, $P_b$ [Notes (1), (2), and (3)]</td>
<td>Elastic [Note (5)]</td>
<td>$1.5S_m$</td>
<td>Elastic [Note (6)]</td>
</tr>
<tr>
<td>Membrane and Bending, $Q$ [Notes (1) and (4)]</td>
<td>Limit analysis [Note (9)]</td>
<td>$0.67L_L$</td>
<td>$3S_m$</td>
</tr>
<tr>
<td>or Test [Note (11)] (NG-3228.4)</td>
<td>or</td>
<td>or</td>
<td>Elastic plastic fatigue [Notes (7) and (8)] (NG-3222.2)</td>
</tr>
<tr>
<td>or Limit analysis [Note (9)]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$S_m$ Elastic [Note (5)]

$P_m + P_b + Q + F$

$S_a$ Elastic fatigue [Notes (7) and (8)]

$P_m + P_b + Q + F$

$S_a$ Elastic plastic fatigue [Notes (7) and (8)] (NG-3222.2)
### Criteria of Stress Intensities for Service Level C

**FIG. NG-3224-1  STRESS CATEGORIES AND LIMITS OF STRESS INTENSITIES FOR SERVICE LEVEL C**

<table>
<thead>
<tr>
<th>Stress Category</th>
<th>Primary Stresses</th>
<th>Secondary Stresses Membrane and Bending, Q</th>
<th>Peak Stresses,</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level C [Note (4)]</td>
<td>Membrane, (P_m) [Notes (1), (2), and (3)]&lt;br&gt;1.5(S_m) or (L_L) or 1.5(S_m) or 0.6(L_e) or Stress-ratio analysis [Note (10)]</td>
<td>Elastic analysis [Note (5)]&lt;br&gt;Limit analysis [Note (6)]&lt;br&gt;Plastic analysis [Note (7)]&lt;br&gt;Test [Note (9)]&lt;br&gt;Stress-ratio analysis [Note (10)]</td>
<td>Evaluation not required</td>
</tr>
<tr>
<td></td>
<td>Bending, (P_b) [Notes (1), (2), and (3)]&lt;br&gt;2.25(S_m) or (L_L) or 2.25(S_m) or 0.5(S_u) or 0.6(L_e) or Stress-ratio analysis [Note (10)]</td>
<td>Elastic analysis [Note (5)]&lt;br&gt;Limit analysis [Note (6)]&lt;br&gt;Plastic analysis [Notes (7) and (8)]&lt;br&gt;Test [Note (9)]&lt;br&gt;Stress-ratio analysis [Note (10)]</td>
<td></td>
</tr>
</tbody>
</table>
Criteria of Stress Intensities for Service Level D

- ASME BPVC Section III - Rules for Construction of Nuclear Facility Components
  - Appendices (F-1440 Core Support Structure)
  - Elastic Analysis, Plastic Analysis, Buckling Analysis,…
  - Primary Membrane Stress
    \[ P_m < \text{Min (2.4 Sm, 0.7 Su)} \]
  - Local Membrane Stress
    \[ P_L < \text{Min (3.6 Sm, 1.05 Su)} \]
  - Local Membrane Stress + Primary Bending Stress
    \[ P_L + P_b < \text{Min (3.6 Sm, 1.05 Su)} \]
  - Average Shear Stress
    \[ V < 0.42 \text{ Su} \]

Free Body Diagram
Design Factors for Welding Locations
Deformation Limit at Service Level D

80% of Deflection Limit
Material of Reactor Internals

- **General Material of Reactor Internals**
  - **304 Stainless Steel (Austenitic)**
    - 18Cr−8Ni (18~20Cr, 8~10.5Ni, 0.08C Max)
    - Avoidance from Sensitization, Compatible with Coolant (Boric Acid Condition)
    - 304L SS (18~20Cr, 8~10.5Ni, 0.03C Max)

- **Alignment Key, Pin**
  - SA638 GR660 (25Ni−15Cr−2Ti), High Strength Material

- **Shim**
  - SA312 TP XM−19 (21~23Cr, 11~13Ni, 0.06C)
  - SA478 S21800 (16~18Cr, 8~9Ni, 0.10C)

- **Holddown Ring**
  - SA182 Grade F6NM (Martensitic), Poor Weldability

- **Flow Skirt**
  - Alloy 690, Good Weldability to Reactor Vessel, Good Weldability, Thermal Expansion Coefficient ~ Reactor Vessel
ASME Material Specifications

- **SA 182**: Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service
- **SA 240**: Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications
- **SA 312**: Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes
- **SA 193**: Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications
- **SA 194**: Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service
- **SA 213**: Seamless Ferritic and Austenitic Alloy-Steel Boiler, Super-heater, and Heat-Exchanger Tubes
- **SA 479**: Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels
- **SA 638**: Precipitation Hardening Iron Base Super-alloy Bars, Forgings, and Forging Stock for High-Temperature Service
- **SA 453**: High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels
## Material Specifications at 650°F or 340°C

<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s Modulus (E)</th>
<th>Yield Strength (Sy)</th>
<th>Design Stress Intensity (Sm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDF A240 TP 304 (RVI)</td>
<td>173 GPa</td>
<td>124 MPa</td>
<td>111 MPa</td>
</tr>
<tr>
<td>MDF A240 TP 316</td>
<td>173 GPa</td>
<td>127 MPa</td>
<td>114 MPa</td>
</tr>
<tr>
<td>SA638 TP 660 (Key, Pin)</td>
<td>177 GPa</td>
<td>532 MPa</td>
<td>284 MPa</td>
</tr>
<tr>
<td>MDF A182 Grade F6NM (HDR)</td>
<td>178 GPa</td>
<td>532 MPa</td>
<td>236 MPa</td>
</tr>
<tr>
<td>MDF A182, TP XM-19 (Shim)</td>
<td>174 GPa</td>
<td>253 MPa</td>
<td>202 MPa</td>
</tr>
<tr>
<td>Alloy 690 (Flow Skirt)</td>
<td>190 GPa</td>
<td>190 MPa</td>
<td>161 MPa</td>
</tr>
<tr>
<td>MDF A508 class 3 (RPV)</td>
<td>172 GPa</td>
<td>286 MPa</td>
<td>184 MPa</td>
</tr>
</tbody>
</table>
## Thermal Expansion Coefficients at 340°C

<table>
<thead>
<tr>
<th>Material Specification</th>
<th>Thermal Expansion Coefficient ($\alpha$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA240 TP304 (RVI)</td>
<td>17.15 E-6</td>
</tr>
<tr>
<td>SA240 TP321 (Ti)</td>
<td>17.10 E-6</td>
</tr>
<tr>
<td>SA638 Type 660 (Alignment Pin)</td>
<td>16.09 E-6</td>
</tr>
<tr>
<td>SA487 F6NM (Holddown Ring)</td>
<td>11.75 E-6</td>
</tr>
<tr>
<td>Alloy 690 (Flow Skirt)</td>
<td>14.80 E-6</td>
</tr>
<tr>
<td>SA508 class 3 (Pressure Vessel)</td>
<td>13.36 E-6</td>
</tr>
</tbody>
</table>

- **Reactor Vessel Thermal Expansion**
  \[ \alpha \Delta T L = (13.36 \times 10^{-6}) \times (340°C - 20°C) \times 12380 \text{ mm} = 52.93 \text{ mm} \]

- **CSB Thermal Expansion**
  \[ \alpha \Delta T L = (17.15 \times 10^{-6}) \times (340°C - 20°C) \times 12380 \text{ mm} = 67.94 \text{ mm} \]
Type of Drawings

- **Sketch**: Initial Design Status, Conceptual Sketch
- **Component Drawing**: Part Drawings → 3D Model
- **Assembly Drawing**: Assembled Configuration, Assembly Method, Assembled Dimension, Required Gap Tolerance
- **Interface Drawings**: Neighboring Structure, Interference Check, Gap, Installation Check
- **Fabrication Drawing**: Accessibility Check, Considering Machining Tool & Manufacturing Process, Jig Design
- **As-built Drawing**: Fabricated Final Dimensions
- **P&ID (Piping and Instrument Drawing)**: Graphical View
- **BOM (Bill of Materials)**: Summary of Materials by Parts
Drawing Skill (1)

- Drawings tell all of mechanical design.
- Requirements of Code and Technical Standards (KS, ANSI, ISO,…)
- Dimensions shall not be dropped and repeated.
Drawing Skill (2)

- Insert Measurable Dimensions if Possible
- Avoid Accumulation of Tolerances.
- Insert Appropriate Datum.
Drawing Skill (3)

- Describe Assembly Method and Inspection Method.
- Dimensions and Description shall be Placed Outside of Item if Possible.
Drawing Skill (4)

- Choose Appropriate Sections and Views.
- Omit Unnecessary Parts.
- Use Appropriate Scale.
  (Scale: 1/2, ¼, 2, 4, 8,..10)
Drawing Skill (5)

- Specify whether it shows before deformation or after deformation.
- All dimensions are based on the room temperature (20°C)
Technical Skill of Design (1)

- Chamfer and Fillet Design for Installation, Retrieval, Disassembly, Anti-Crack Initiation
Technical Skill of Design (2)

- Snubber Design for Assembly – Tongue & Groove

- restriction of excessive radial and torsional movement by 6 snubbers
Technical Skill of Design (3)

- Weld for Avoid Crack Initiation → Full Penetration Weld (o), Fillet Weld (x)
Technical Skill of Design (4)

- Smooth Curve \(\rightarrow\) Reduce Stress Concentration
Technical Skill of Design (5)

- Consideration of Weld Shrinkage → Reduce Weld
Technical Skill of Design (6)

- Consideration of Thermal Expansion
Technical Skill of Design (7)

- Guide Tube Design for Smooth Insertion
Technical Skill of Design (8)

- Reinforce in Nozzles and Flange.
Technical Skill of Design (9)

- Transportation & Handling for Heavy Weight
Technical Skill of Design (10)

- Consideration of Assembly, Disassembly and Retrieval.
- Consideration of Installation, Maintenance, Inspection and Repair
Technical Skill of Design (11)

• Combine Functions → Fuel Springs of Fuel Assembly

- Spring
- Passage for Control Rod
- Support Point
Technical Skill of Design (12)

- **Separate Functions: Thermocouple Nozzle**

![Diagram of Thermocouple Nozzle]

- Sheathed Thermocouple (DP1)
- Compression Fitting (DP4)
- Seal by Welding (DP3)
- RV
- Inside
- Outside
- Cladding by Mechanical Rolling (DP2)
- Fitting (DP4)
- Seal by Welding (DP3)
- Thread
SMART

Hvala

Thank you

Any Questions?