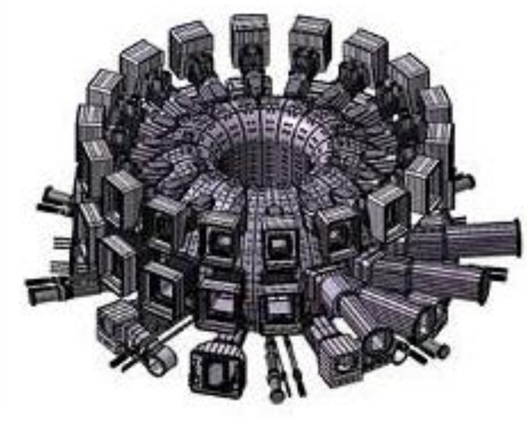
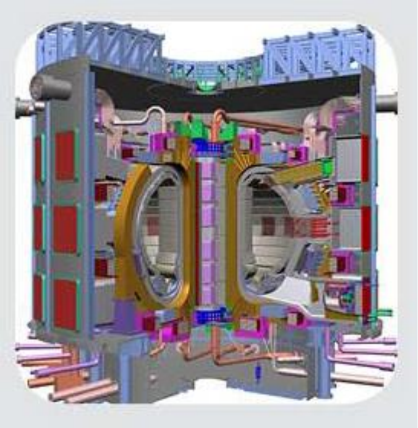
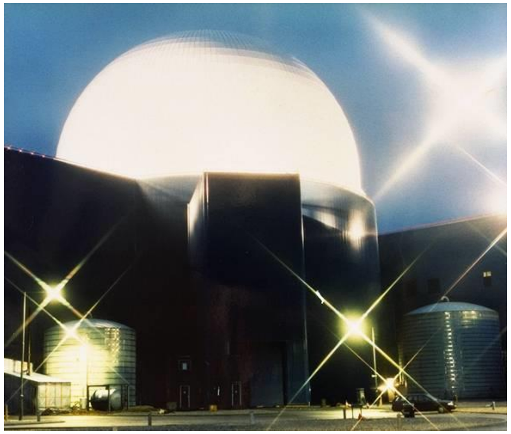
Harmonising Nuclear Codes and Standards for Mechanical Components

Professor Nawal K Prinja BSc, MSc, PhD, CEng, FIMechE
Technical Director, Clean Energy, AMEC Foster Wheeler
Chair of Mechanical Codes & Standards Task Force, CORDEL, WNA







4TH MDEP CONFERENCE on New Reactor Design Activities
SESSION 1: “CODES AND STANDARDS HARMONIZATION”
12-13 SEPTEMBER, LONDON

Contents

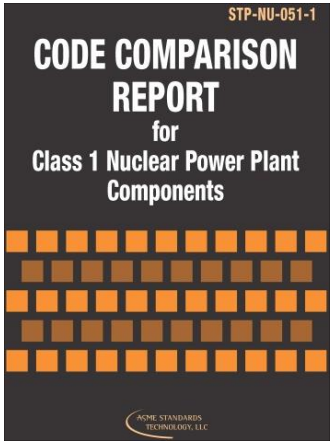
- **Need for harmonisation**
- **How it is being achieved**
- **What has been achieved by MCSTF of WNA/ CORDEL**
- **Current and future work**

Cooperation in Reactor Design Evaluation and Licensing (CORDEL) has a mission to promote the standardization of nuclear reactor designs within a harmonized nuclear regulatory environment. Its **Mechanical Codes and Standards Task Force (MCSTF)** plays a key role in harmonisation of codes and standards.

MDEP's Code Comparison Project

Main Reasons for Differences in the Mechanical Codes & Standards

- General Requirement Practices
  - Quality Assurance Requirements (NQA-1, ISO 9001, IAEA 50/SG)
  - Conformity Assessment (Stamping, RPE)
  - Local qualifications for welding and NDE
  - Local reference materials
- Scope of Codes
  - CSA – Candu reactors
  - AFCEN – PWR
  - ASME, JSME, KEA, and CSA – BWR, PWR, Candu
- Flexibilities allowed due to variation in country practices
  - Operational experience (prescribed in AFCEN)
  - Design and Analysis Flexibility (analysis methodology specified in AFCEN)



STP-NU-051-1

CODE COMPARISON REPORT
for
Class 1 Nuclear Power Plant Components

ASME STANDARDS TECHNOLOGY, LLC

Example: Assessing Pressure Vessel to American ASME and Russian PNAE G 7-002-86

Sizing Related:
Russian Nominal Allowable Stress = $[\sigma]$ = Minimum $(\sigma_{UTS}/2.6, \sigma_{YS}/1.5)$
ASME Design Stress Intensity = Sm = Minimum$(\sigma_{UTS}/3, \sigma_{YS}/1.5)$

Pri. Membrane Russian	Pri. Membrane ASME
For NOC < $[\sigma]$	For Level A < Sm
For AOO < 1.2 $[\sigma]$	For Level B < 1.1 Sm
For DA < 1.4 $[\sigma]$	For Level C < 1.2 Sm
Hydro Test < 1.35 $[\sigma]$	For Level D < 2.4 Sm or 0.7 UTS
	Hydro. Test < 0.9 σYS

Example presented by Dr Vaze of BARC

Estimating VVER1000 RPV Thickness

RPV Thickness Calculation using ASME NB and PNAE G 7-002-86

- Russian Nominal Allowable Stress

[σ]=Minimum(539/**2.6, 441/1.5)=207.3 Mpa**

- ASME Design Stress Intensity

Sm = Minimum(539/**3, 441/1.5)= 179.7**

– ASME: Minimum thickness required=214 mm
– PNAE : Minimum thickness required=185 mm
– Actual thickness provided = 192.5 mm

- Although actual thickness is less than the minimum required by ASME: **Is design less safe ? May or may not be**

Should we apply ASME equation to Russian design?

Harmonization of Safety Levels

Failure modes and the knowledge of Mechanics used are universal

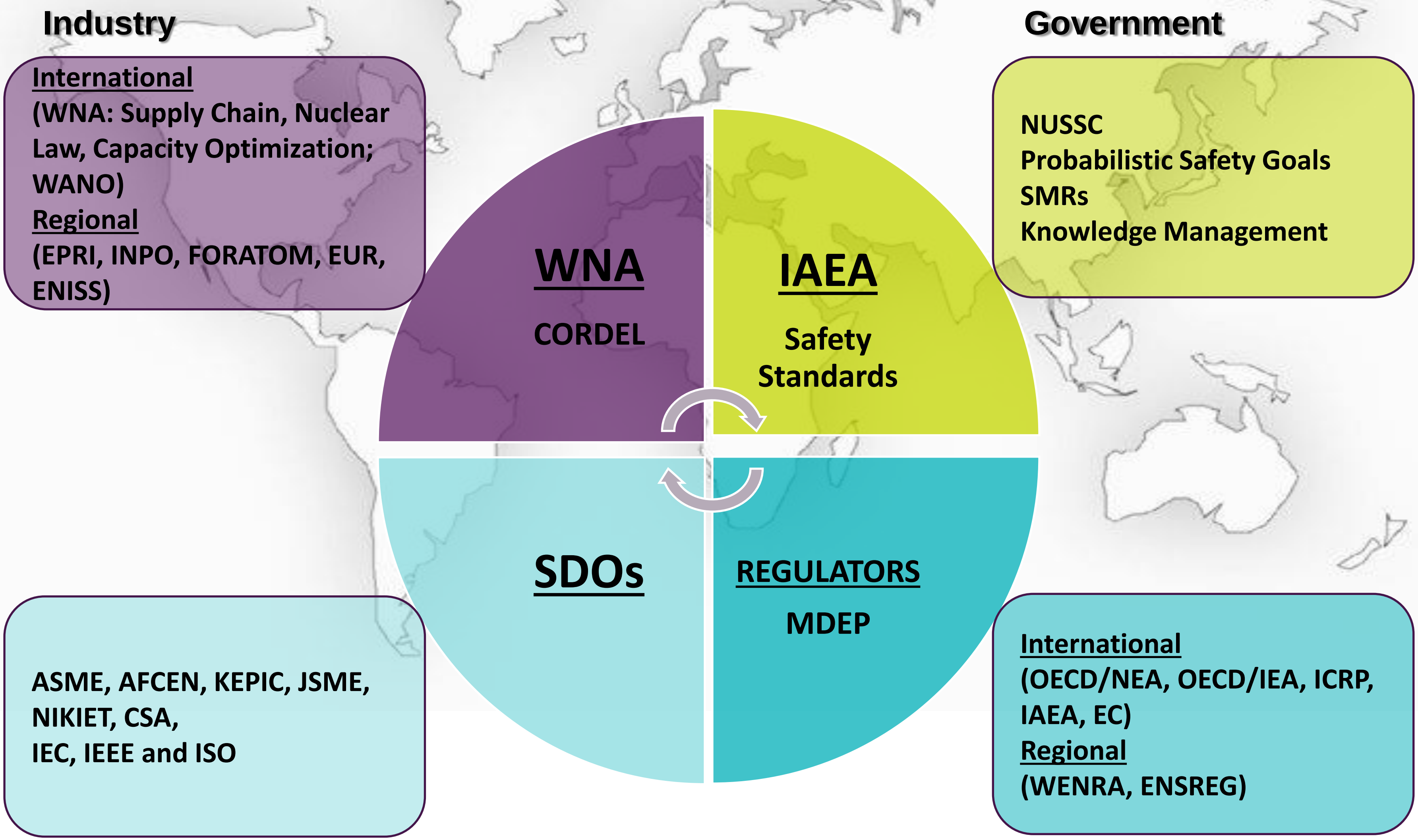
But code rules differ because of :-

- Regulatory Requirements and Limitations
- Local Industry Practices
- Qualifications of welders, NDE/T personnel and professional Engineers
- QA and compliance requirements
- Scope Differences

International Harmonisation

- **Applicable and internationally recognized set of Safety requirements**
  - IAEA standards underpin safety in all countries
    - Higher level in standards hierarchy, not enforceable
    - Supplemented by enforceable national regulations
- Need harmonisation of more detailed requirements
- Need also an effort on the Industry side:
  - Codes and Standards that are recognised as equivalent by industry (necessary for acceptance being considered by regulatory bodies).
  - A harmonisation effort is required to identify differences and recognised equivalences between major codes.

International Cooperation Framework



Industry

International
(WNA: Supply Chain, Nuclear Law, Capacity Optimization; WANO)
Regional
(EPRI, INPO, FORATOM, EUR, ENISS)

Government

NUSSC
Probabilistic Safety Goals
SMRs
Knowledge Management

WNA

CORDEL

IAEA

Safety Standards

SDOs

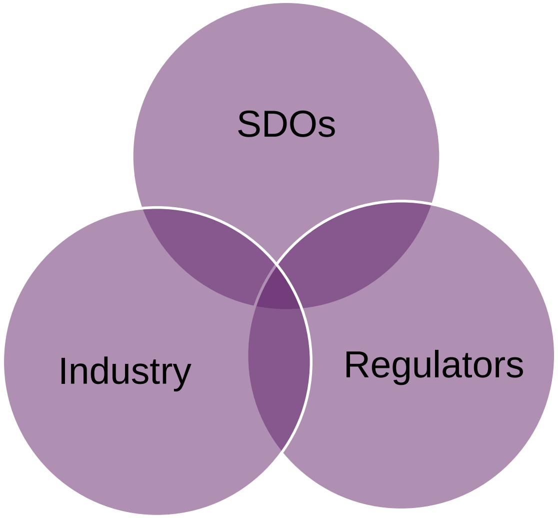
REGULATORS

MDEP

ASME, AFCEN, KEPIC, JSME, NIKIET, CSA,
IEC, IEEE and ISO

International
(OECD/NEA, OECD/IEA, ICRP, IAEA, EC)
Regional
(WENRA, ENSREG)

Promotion of Harmonization of Standards and Codes



Regulators: MDEP

- Canada, Finland, France, Indi, Japan, Russian Federation, South Africa, the UAE, The UK, the USA, China, and Sweden
- 1 common position and four technical reports

Standard Development Organizations: SDO Board

- ASME BPVC III div.1, AFCEN (RCC-M), KEA (KEPIC), JSME (S-NC1), CSA,(N285.0) NIKIET (PNAE-G7)
- Code Comparison Report - STP-NU-051

http://files.asme.org/STLLC/31181.pdf

Industry: WNA CORDEL

- The international voice of the industry promoting convergence of nuclear design codes

Mechanical Codes & Standards Task Force

One of the Task Forces of CORDEL set up by the WNA

Aim: To promote the convergence of nuclear mechanical codes and standards in order to facilitate the international standardization of reactor designs:

- ***For one component designed to a specific code to be easily exportable***
- ***Harmonization of requirements of codes & standards***
- ***Acceptance that international codes can be used to meet regulatory requirements***

Membership: Major international reactor vendors, large international utilities, engineering consulting companies and code users.

Harmonisation Work Plan of CORDEL MCSTF

Select topics with input from:
- Industry (CORDEL)
- Regulators (MDEP-CSWG)
- SDOs (Convergence Board)

Convene group of experts from the industry to work within CORDEL MCSTF

Report current status of codes

Propose harmonised rules

Define common Code Case

CORDEL MCSTF Projects

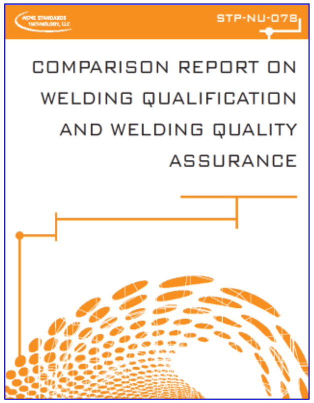
Finalised Projects

- **Certification of NDE Personnel – *Published 2015*** ✓
- **Comparison Report on Welding Qualification and Welding Quality Assurance – STP-NU-078 – *Published 2016*** ✓

On-Going Projects

Non-linear analysis design rules

- **Part 1: Code comparison – *Published February 2017*** ✓
- **Part 2: Industry Practices – *First draft available***
- **Part 3: Benchmark – *Workshop to review results to be held in early 2018***



STP-NU-078

COMPARISON REPORT ON WELDING QUALIFICATION AND WELDING QUALITY ASSURANCE

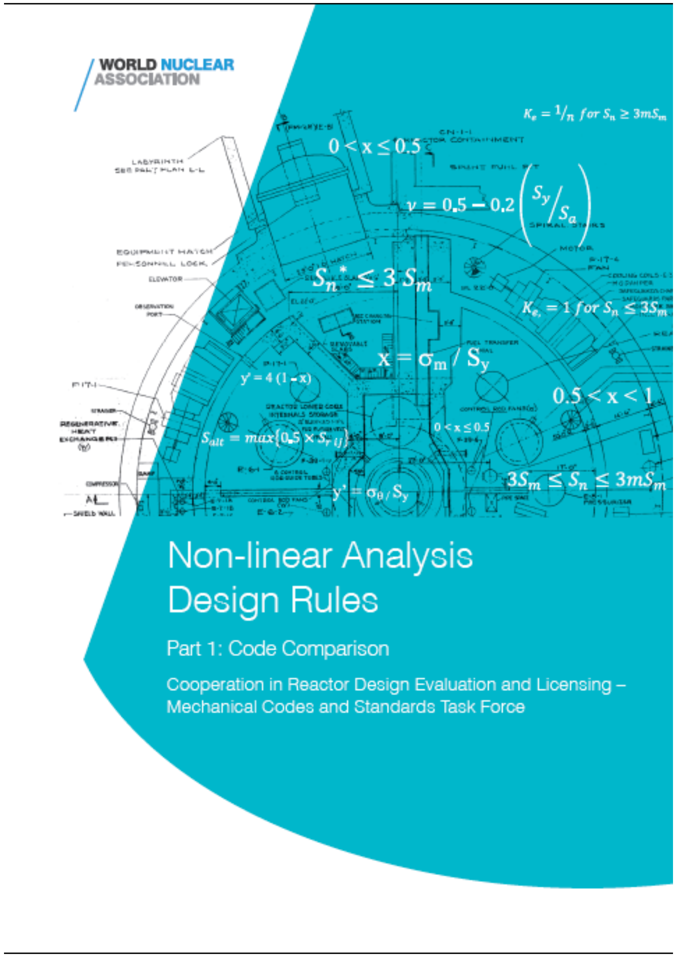
Harmonisation of Fatigue Life Analysis Methods

- **Part 1: Comparison of Pressure Vessel and Piping Fatigue Design Rules based on S-N (cyclic stress vs. cycles to failure) Approach – *under drafting***
- **Part 2: Proposed Harmonized Pressure Vessel and Piping Fatigue Design Rules**
- **Part 3: Proposed Harmonized Fatigue Crack Growth Analyses**
- **Part 4: Proposed Harmonized Environmental Effects on Fatigue and Fatigue Crack Growth Analysis**

Non-linear analysis design rules

- **Question:** **How to improve Pressure Equipment Code rules considering nonlinear behavior of materials?**
- **Damages Investigated**
  - Plastic collapse / excessive deformation
  - Plastic instability / ultimate load
  - Local Failure
  - Fatigue
  - Plastic shakedown and ratcheting
- **Other aspects: the stress classification rules (reinforced nozzles, elastic follow-up…)**
- **Loads:**
  - Mechanical and thermal
  - Quasi-static, cyclic or dynamic (later)
- **Analysis methods:**
  - Elastic
  - Elastic-plastic monotonic/cyclic
  - Limit load
- **No buckling; no creep; no cracks**

Part 1: Existing Code comparisons



WORLD NUCLEAR ASSOCIATION

Non-linear Analysis Design Rules

Part 1: Code Comparison

Cooperation in Reactor Design Evaluation and Licensing – Mechanical Codes and Standards Task Force

Report Published

Main conclusions:

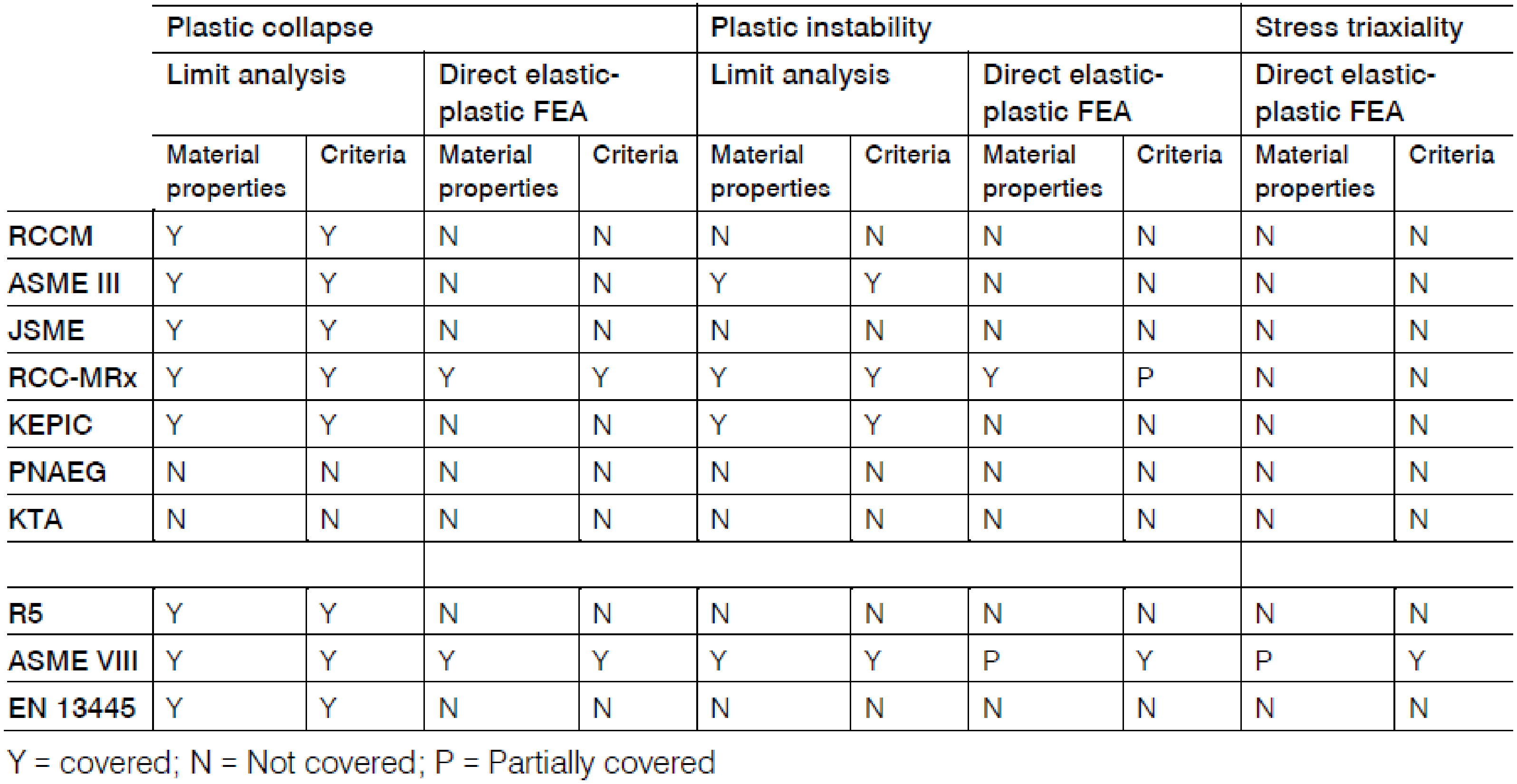
- No Code for the use of non-linear analysis methods to asses for all failure mechanisms
- 2 Codes have more detailed requirements for non-linear analysis:
  - AFCEN RCC-MRx
  - ASME BPVC Section VIII Div. 2
- Large improvements to existing Codes are needed

The report lists:

- Major Open Points
- Major Gaps and Needs

Part 1:Existing Code comparisons

Overview of the non-linear analysis methodologies for **monotonic** loads

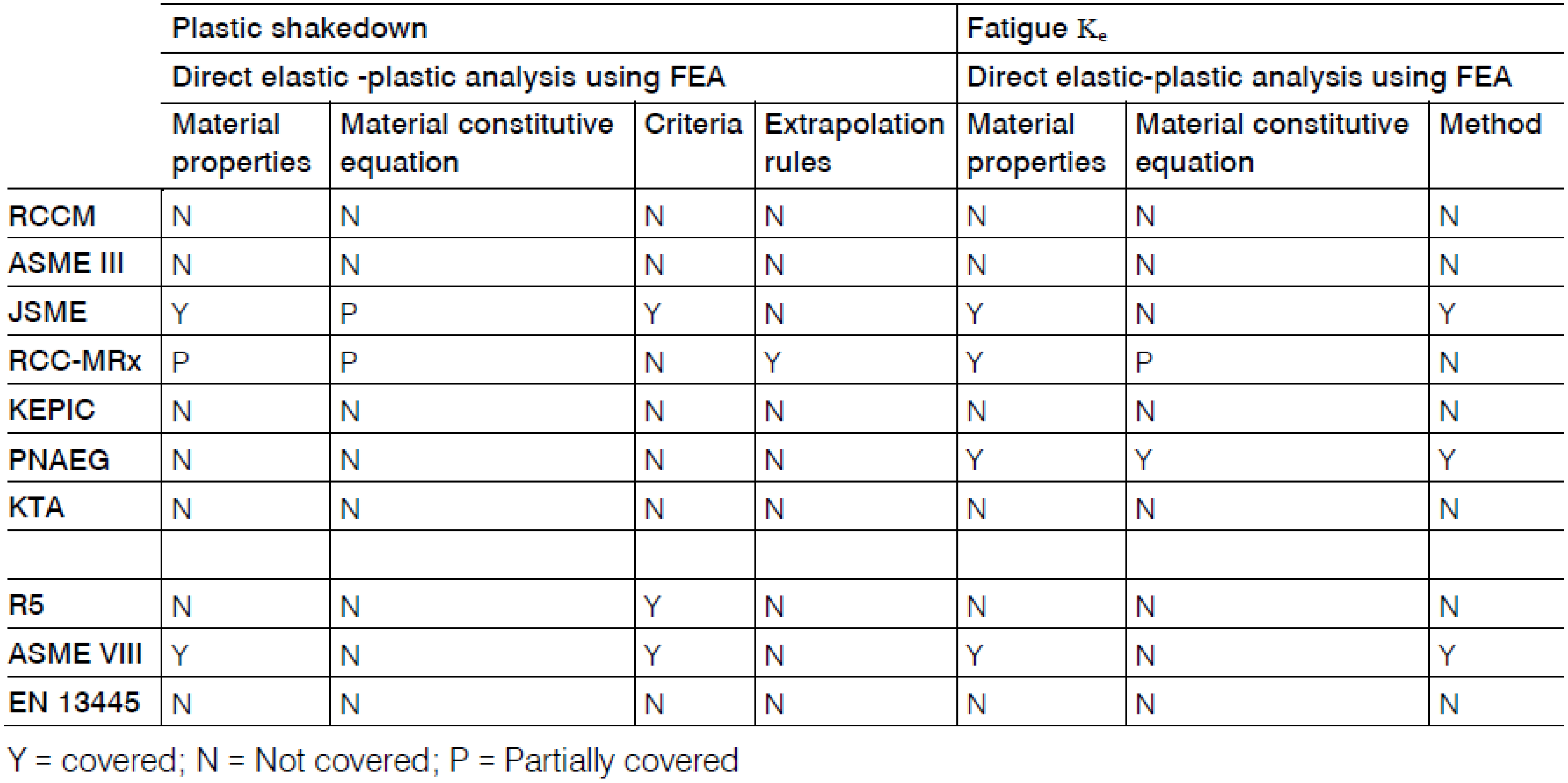


	Plastic collapse				Plastic instability				Stress triaxiality	
	Limit analysis		Direct elastic-plastic FEA		Limit analysis		Direct elastic-plastic FEA		Direct elastic-plastic FEA	
	Material properties	Criteria	Material properties	Criteria	Material properties	Criteria	Material properties	Criteria	Material properties	Criteria
RCCM	Y	Y	N	N	N	N	N	N	N	N
ASME III	Y	Y	N	N	Y	Y	N	N	N	N
JSME	Y	Y	N	N	N	N	N	N	N	N
RCC-MRx	Y	Y	Y	Y	Y	Y	Y	P	N	N
KEPIC	Y	Y	N	N	Y	Y	N	N	N	N
PNAEG	N	N	N	N	N	N	N	N	N	N
KTA	N	N	N	N	N	N	N	N	N	N
R5	Y	Y	N	N	N	N	N	N	N	N
ASME VIII	Y	Y	Y	Y	Y	Y	P	Y	P	Y
EN 13445	Y	Y	N	N	N	N	N	N	N	N

Y = covered; N = Not covered; P = Partially covered

Part 1:Existing Code comparisons

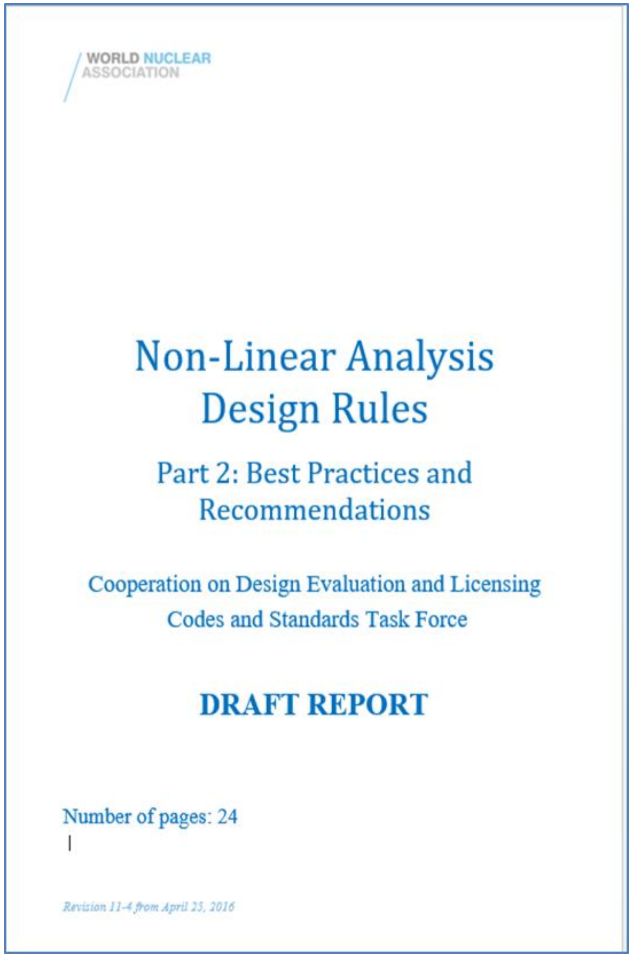
Overview of the non-linear analysis methodologies for **cyclic** loads



	Plastic shakedown				Fatigue K_e		
	Direct elastic -plastic analysis using FEA				Direct elastic-plastic analysis using FEA		
	Material properties	Material constitutive equation	Criteria	Extrapolation rules	Material properties	Material constitutive equation	Method
RCCM	N	N	N	N	N	N	N
ASME III	N	N	N	N	N	N	N
JSME	Y	P	Y	N	Y	N	Y
RCC-MRx	P	P	N	Y	Y	P	N
KEPIC	N	N	N	N	N	N	N
PNAEG	N	N	N	N	Y	Y	Y
KTA	N	N	N	N	N	N	N
R5	N	N	Y	N	N	N	N
ASME VIII	Y	N	Y	N	Y	N	Y
EN 13445	N	N	N	N	N	N	N

Y = covered; N = Not covered; P = Partially covered

Part 2: Recommended practices



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Non-Linear Analysis
Design Rules

Part 2: Best Practices and
Recommendations

Cooperation on Design Evaluation and Licensing
Codes and Standards Task Force

DRAFT REPORT

Number of pages: 24

Revision 11-4 from April 25, 2016

Draft Report available with content:

1. General introduction

- presentation of **"usable"** different methods
- Recommendation to users
- definitions / glossary

2. Proposed rules by damage

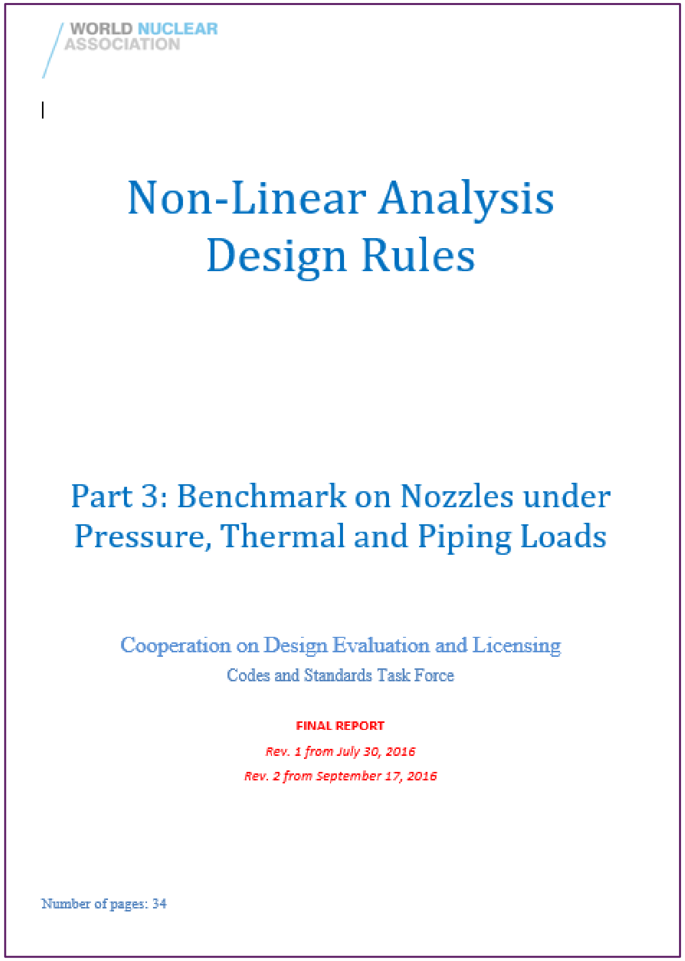
- Step by step approach
- Validation

3. Required Material properties

4. Criteria

5. Quality management

Part 3: Benchmarks



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Non-Linear Analysis Design Rules

Part 3: Benchmark on Nozzles under Pressure, Thermal and Piping Loads

Cooperation on Design Evaluation and Licensing
Codes and Standards Task Force

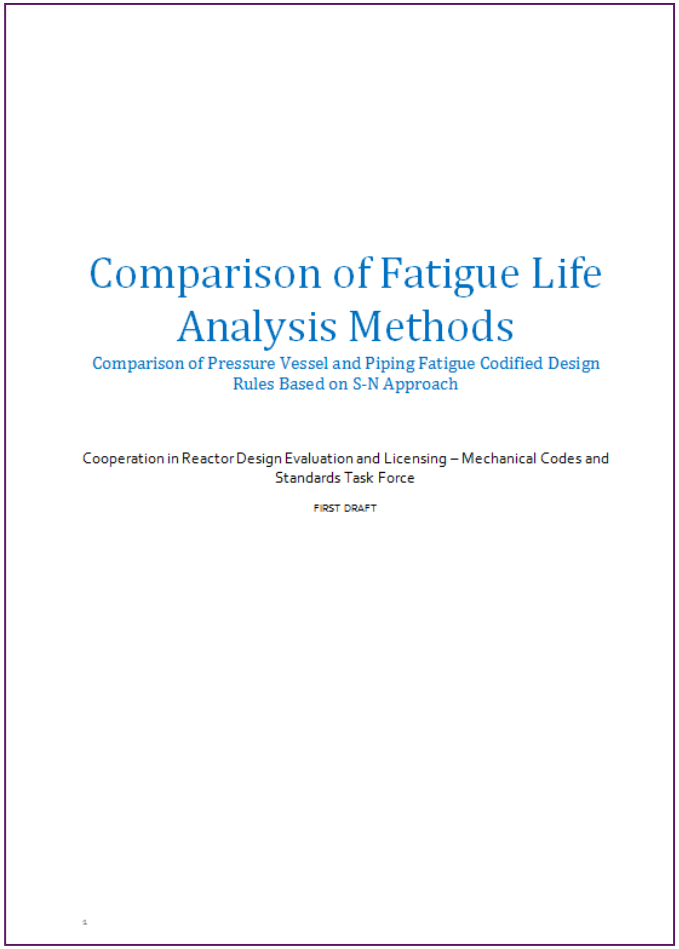
FINAL REPORT
Rev. 1 from July 30, 2016
Rev. 2 from September 17, 2016

Number of pages: 34

- **2 benchmarks to apply and improve "guidelines report"**
  - **Large Low Alloy Steel (LAS) vessel nozzle** under pressure and piping loads
  - **Small Stainless Steel (SS) piping nozzle** under pressure and thermal loads
- **All the data are in the report**
- **Result presentation guidelines are also in the report**

- **Benchmark 1**
  - Elastic codified rules
  - Elastic-plastic
  - Limit loads
- **Benchmark 2**
  - Elastic codified rules
  - Simplified elastic-plastic and K_e in Fatigue
  - Direct cyclic and plastic shake down

Fatigue Life Analysis Methods



Comparison of Fatigue Life Analysis Methods

Comparison of Pressure Vessel and Piping Fatigue Codified Design Rules Based on S-N Approach

Cooperation in Reactor Design Evaluation and Licensing – Mechanical Codes and Standards Task Force

FIRST DRAFT

This report reviews and compares the current code requirements of fatigue analysis and design rules based on the S-N approach in the major nuclear and non-nuclear design codes.

Major nuclear codes:

ASME BPVC Section III NB & NH, AFCEN RCC-M & RCC-MRx, JSME, KEPIC, PNEA and R5.

Selected non-nuclear codes:

ASME BPVC Section VIII Division 2, EN 12952-3 , EN 13445-3 , PD 5500 and JB4732.

Additional Slides

Benchmark problem

Benchmark 1: LAS Vessel nozzle (1/3)

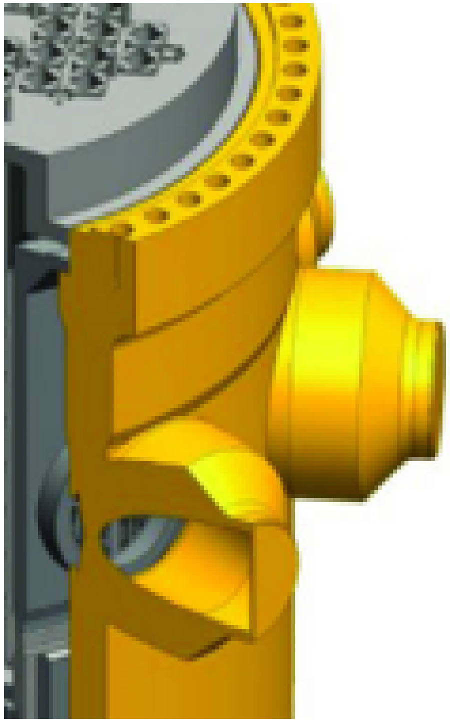
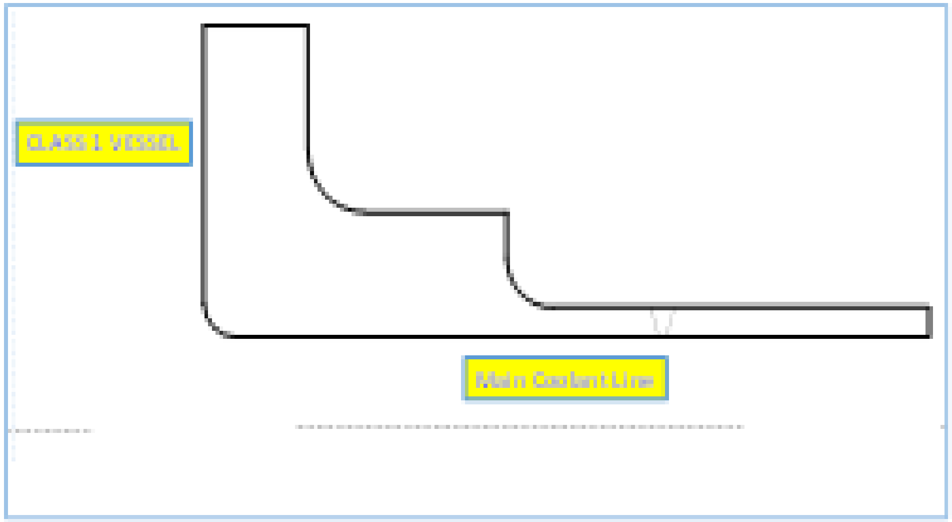


Figure 1: RPV nozzle



Larger schemes available in Appendix 1

Figure 2: Typical class 1 vessel nozzle

- 2D and 3D model
- Loads:
  - Pressure
  - or pressure + piping loads

- **Damages**
  - Plastic collapse
  - Plastic instability
  - Local failure

- Methods
  - Elastic codified rules
  - Elastic-plastic
  - Limit load

Benchmark 1: LAS Vessel nozzle (2/3)

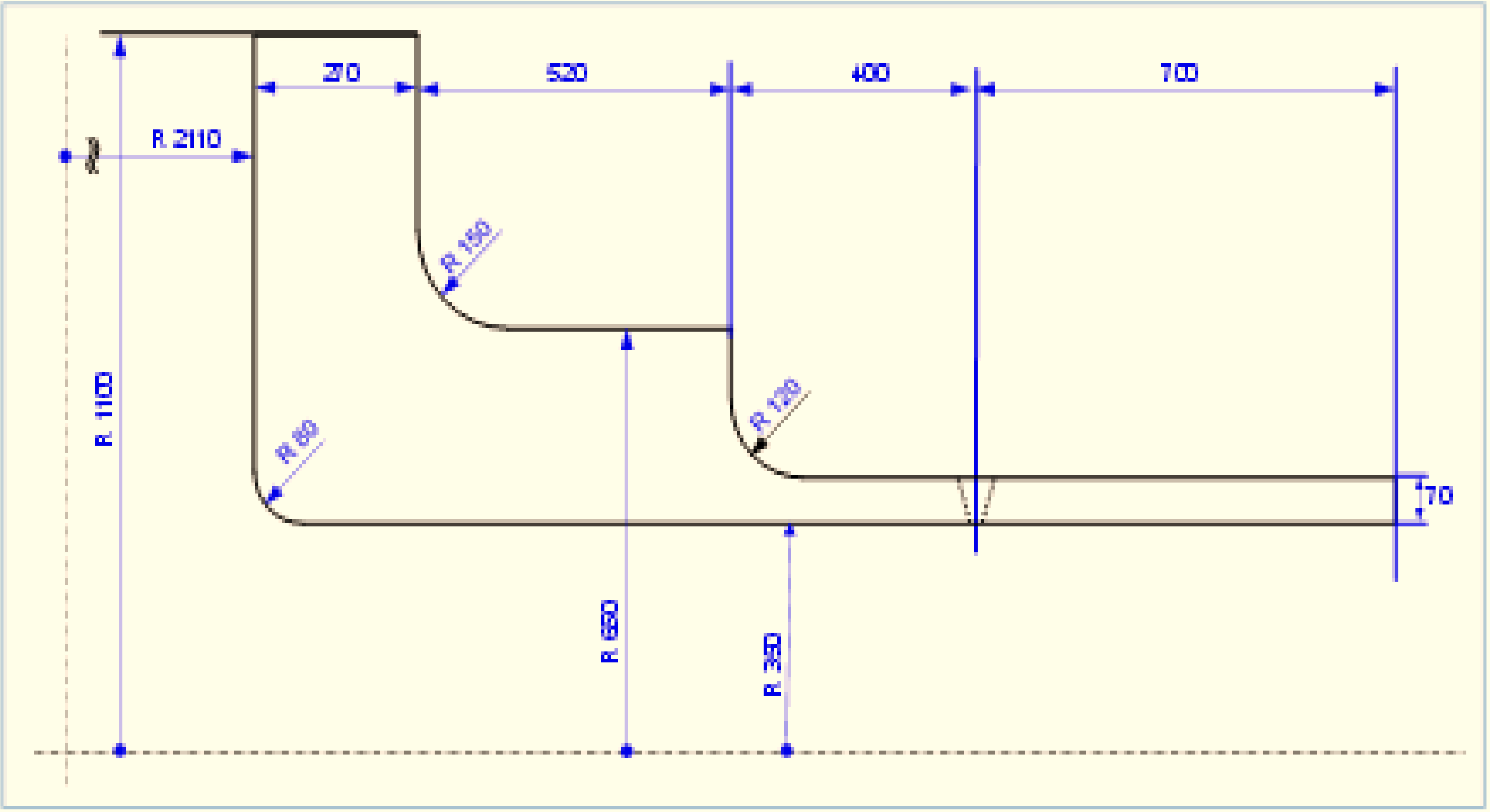
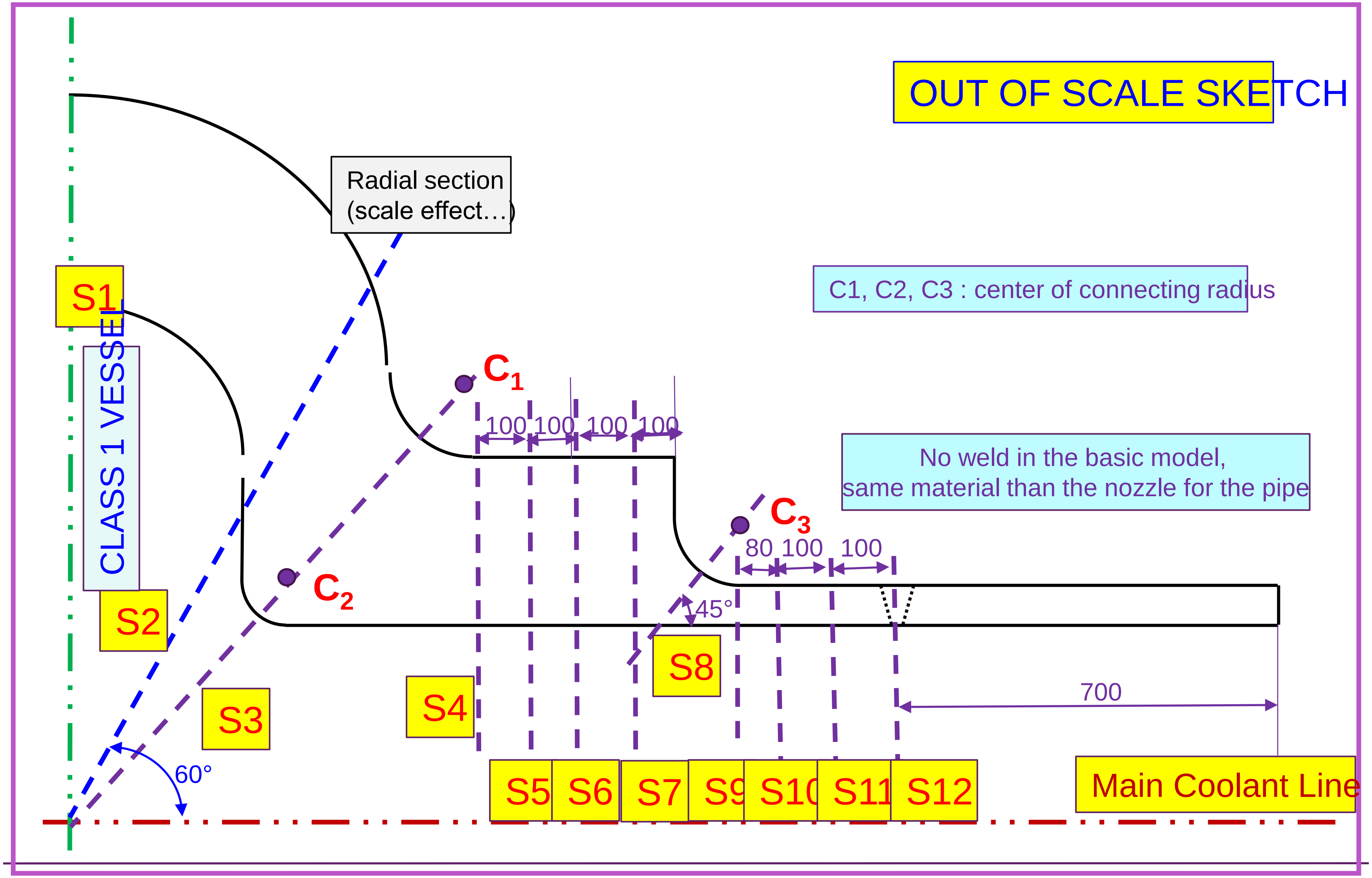


Figure 5: Class 1 Low Alloy Steel Vessel Nozzle – 0° scheme

Benchmark 1: LAS Vessel nozzle (3/3)

- Results presentation



Benchmark 2 : SS Piping Nozzle

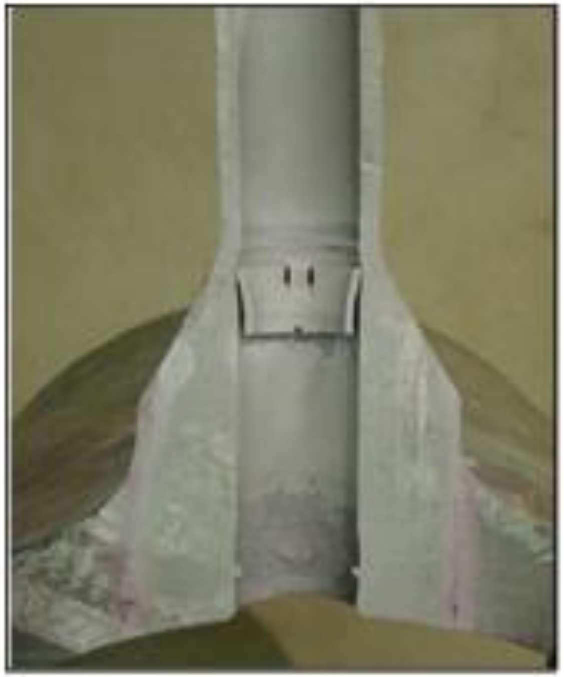
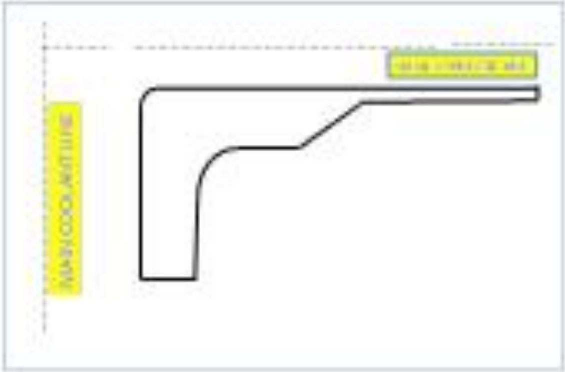


Figure 3: **Main coolant line Nozzle (CVCS)**



Larger schemes available in Appendix 2

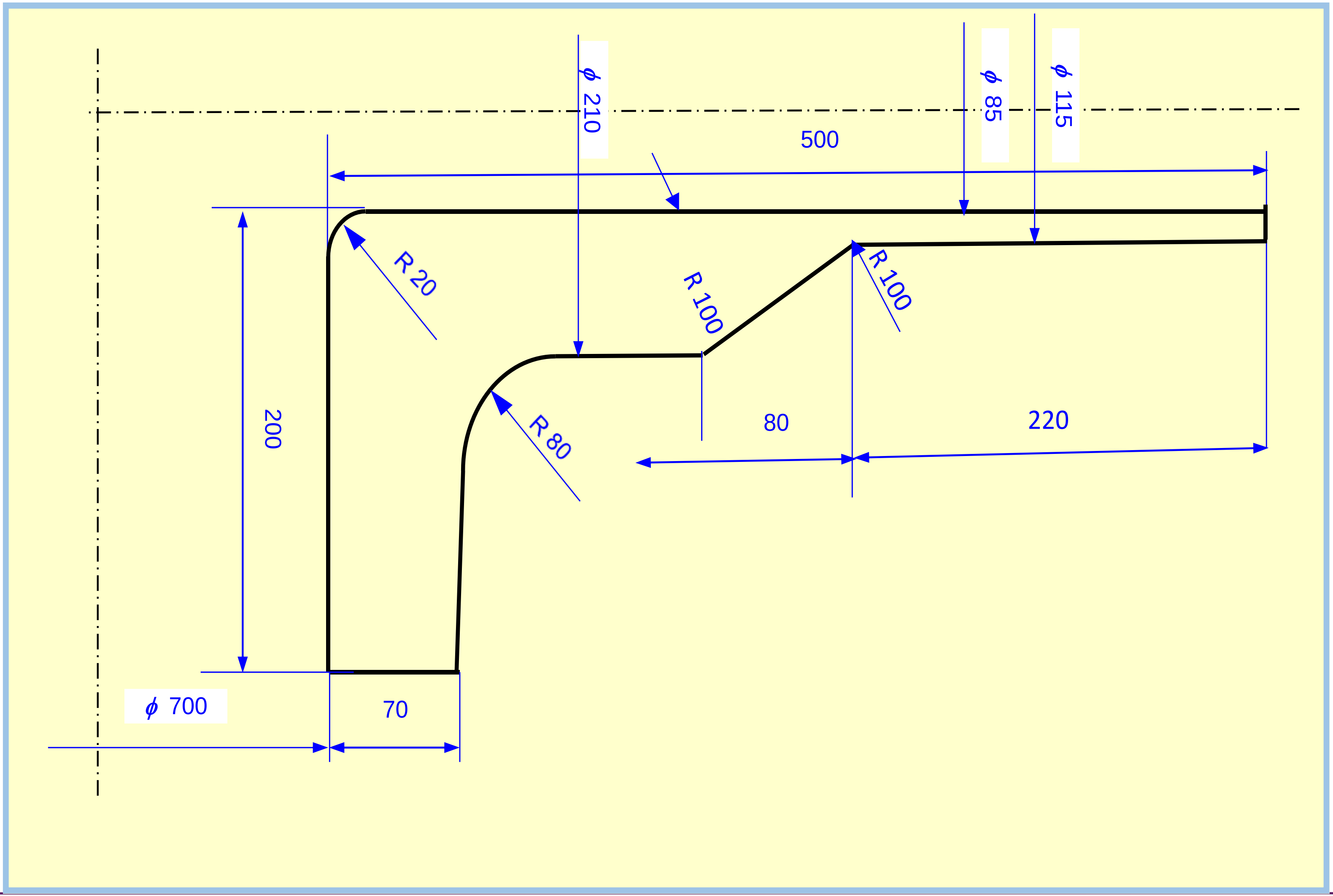
Figure 4: **Typical MCL Stainless Steelnozzle**

- 2D and 3D models
- 2 cyclic thermal shocks
  - 220°C thermal shock 100 cycles
  - 110°C thermal shock 800 cycles

- Damages
  - Fatigue
  - Plastic shakedown

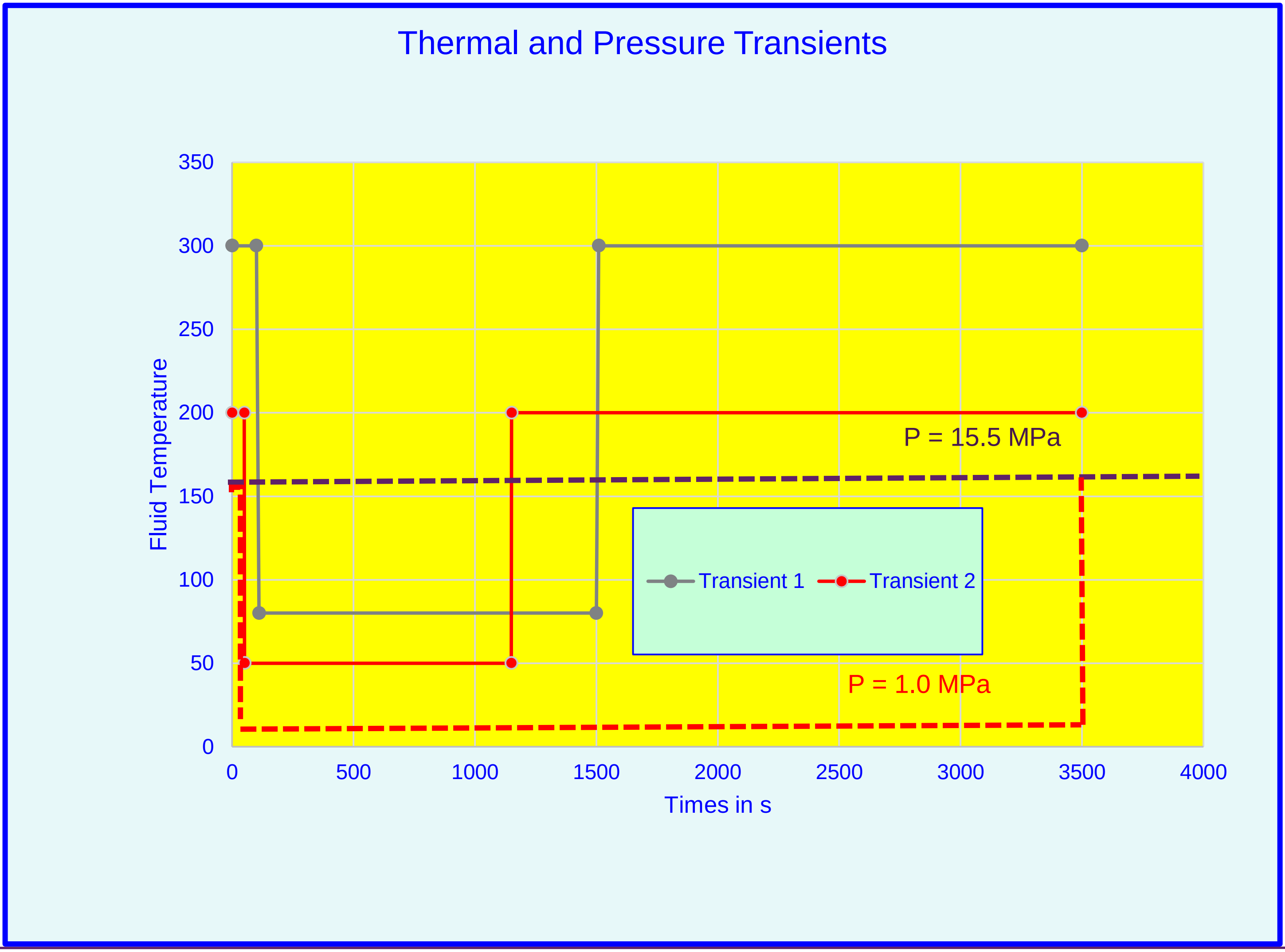
- **Methods**
  - Elastic codified rules
  - Simplified Elastic-plastic: K_e
  - Elastic-plastic evaluation of cyclic strains

Benchmark 2 : SS Piping Nozzle (1/5)



Benchmark 2 : SS Piping Nozzle

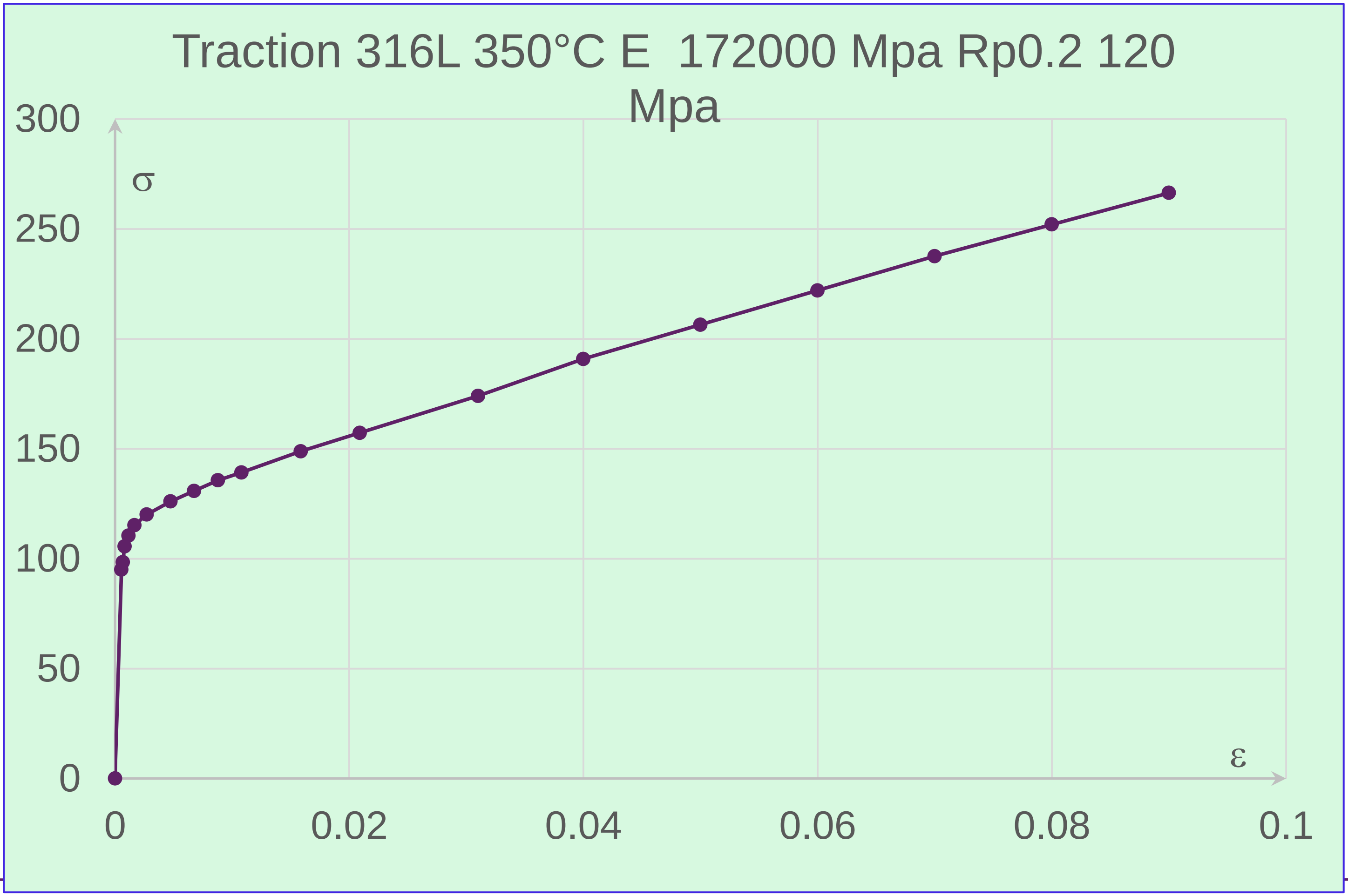
(2/5) - Transients description



Benchmark 2: SS Piping Nozzle

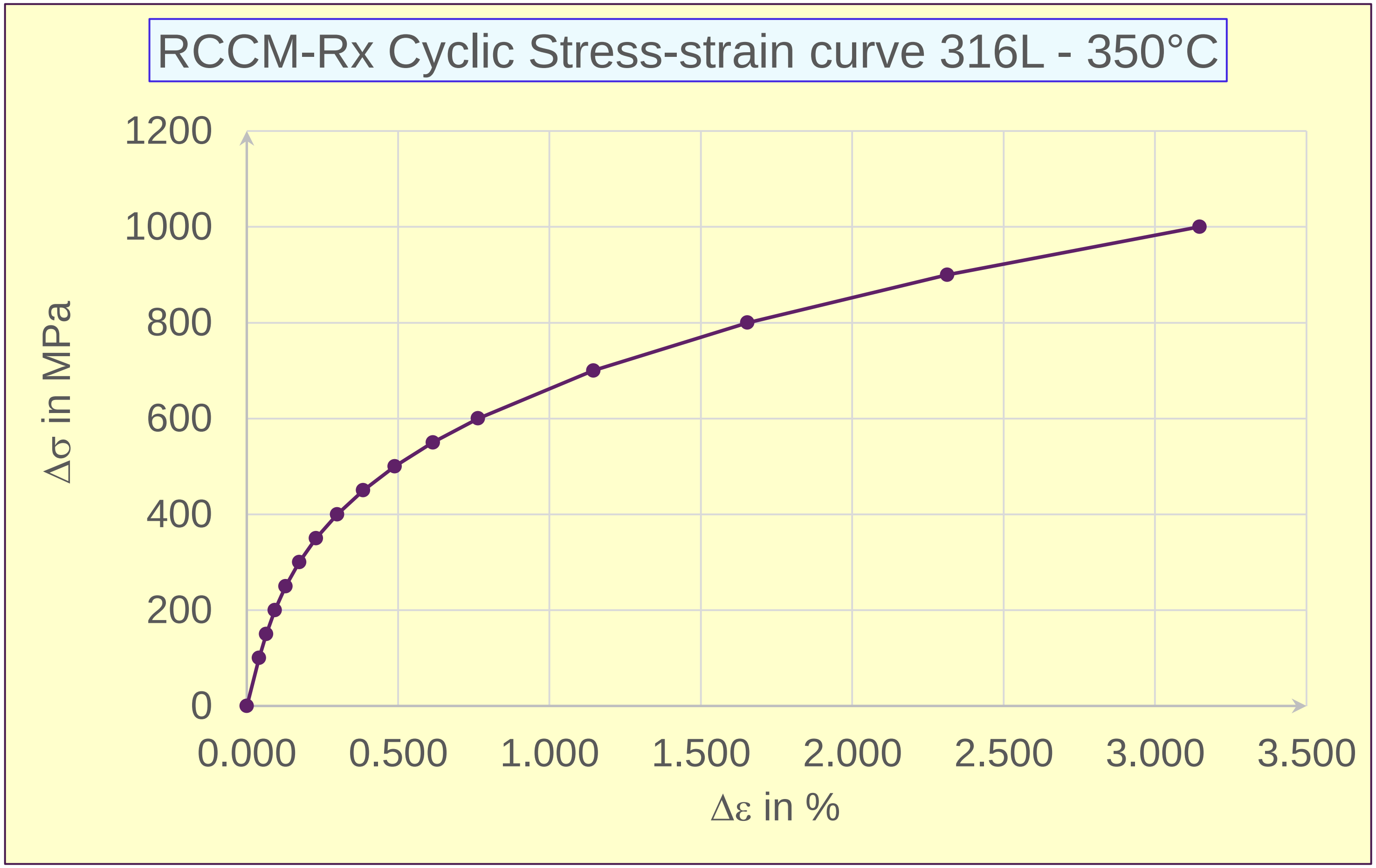
(3/5) - Material properties

Monotonic Stress-Strain curve



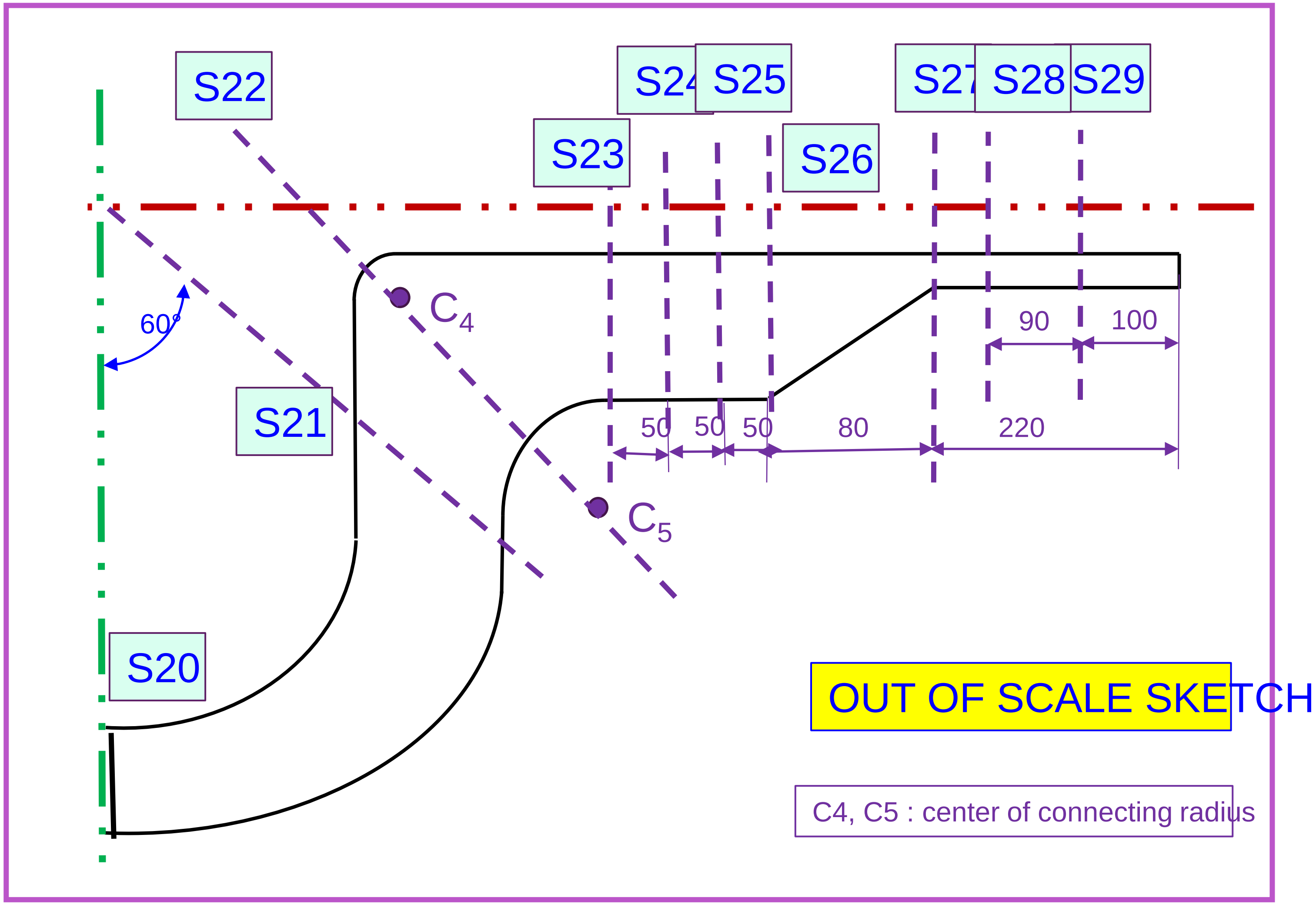
Benchmark 2: SS Piping Nozzle

(4/5) - Material properties



Benchmark 2 : SS Piping Nozzle

(5/5) - Results presentation



OUT OF SCALE SKETCH

C4, C5 : center of connecting radius

Thank You