REACTOR VESSEL MATERIAL AGING MANAGEMENT PROGRAM

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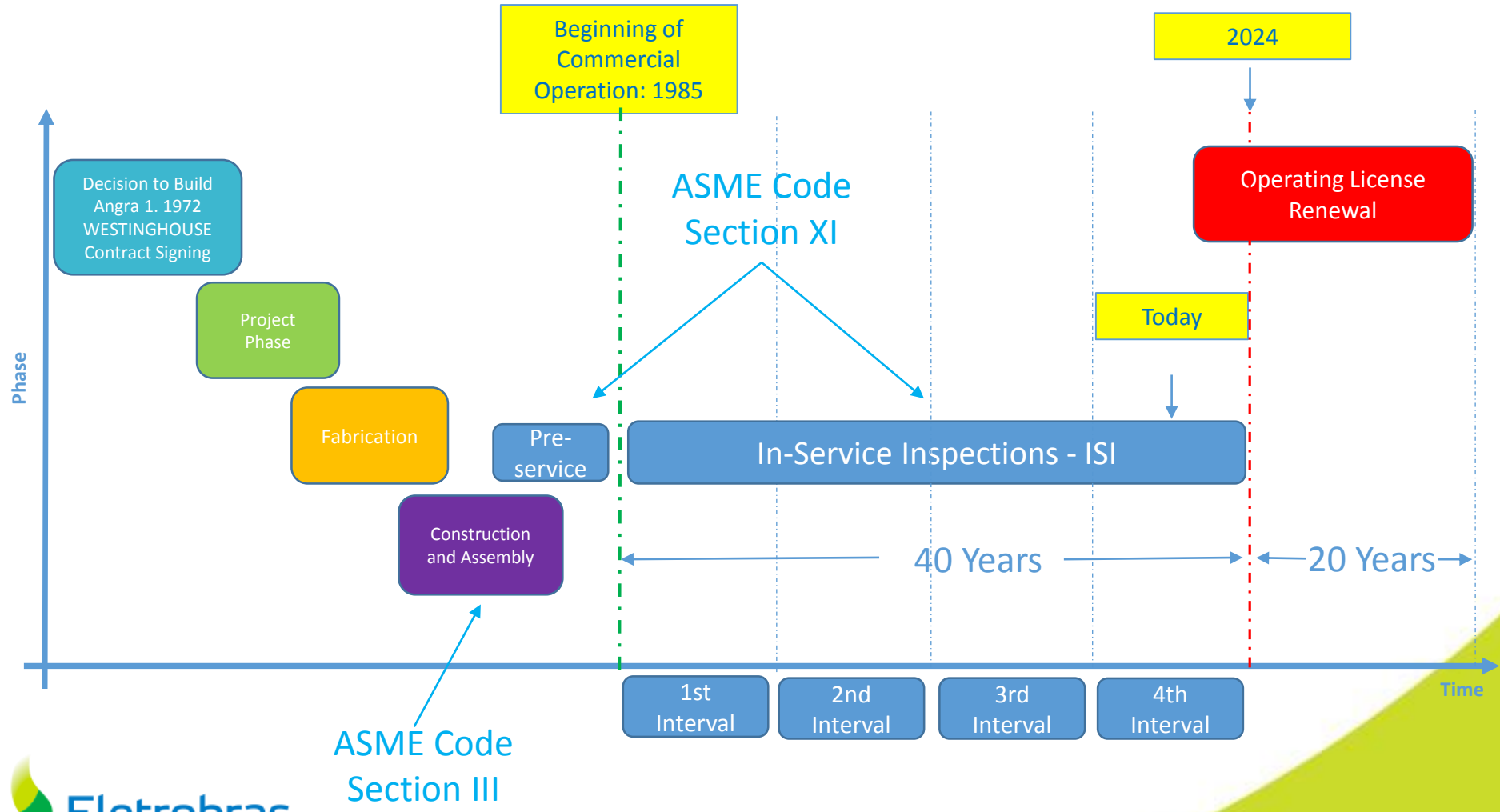
1. Introduction

- Brazilian nuclear power plants are licensed for a period of 40 years in accordance with the rule CNEN NE-1.04, "Licensing of Nuclear Installations", issued by Comissão Nacional de Energia Nuclear (CNEN), the Brazilian regulatory board.
- Licensing process is based on the Authorization to Permanent Operation (AOP)

1. Introduction



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1. Introduction

- The reactor vessel material surveillance aging management program monitors the irradiation embrittlement of the Reactor Pressure Vessel materials from tests performed in specimens contained within surveillance capsules on beltline of reactor pressure vessel.

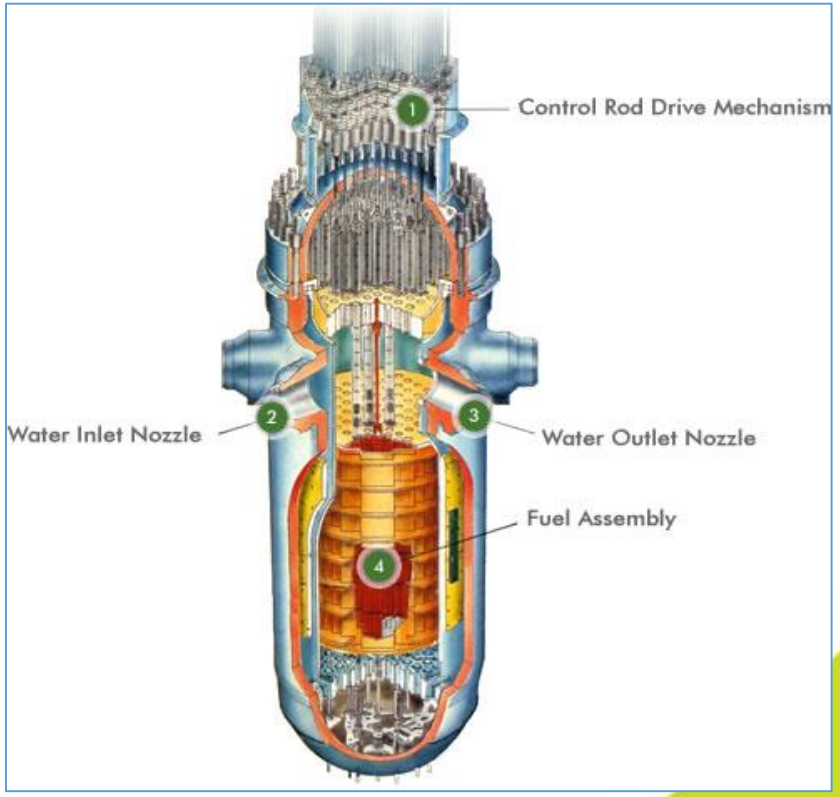

Figure 1. Reactor pressure vessel and its components

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1. Introduction - Requirements

- The Code of Federal Regulations, 10 CFR Part 50, Appendix G 50—Fracture Toughness Requirements;
- The Code of Federal Regulations, 10 CFR Part 50, Appendix H, requires a surveillance program if that the peak neutron fluence at the end of design life of the vessel will exceed 10^{17}n/cm² (E>1MeV);
- The reactor vessel beltline materials must be monitored by a surveillance program to meet the ASTM E185-82 Standard [1].
- At Angra Unit 1, the 10 CFR Part 50, Appendix H requirements are met by the PI-V-22 procedure (Programa de Remoção e Testes dos Corpos de Prova do Vaso do Reator);

1. Introduction

- Six surveillance capsules were inserted in the reactor vessel prior to initial plant start-up;
- Only two surveillance capsules from the Angra 1 reactor pressure vessel have been withdrawn and tested;
- The reactor vessel material surveillance program will use the four remaining capsules during the period of extended operation.

1. Introduction

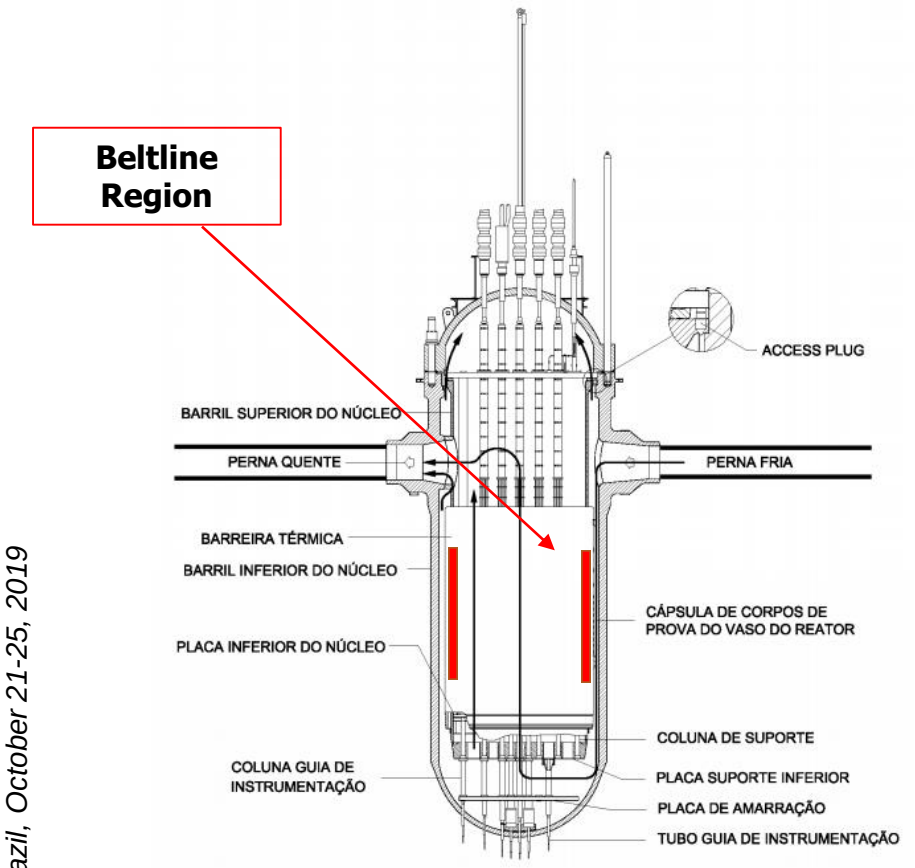

Figure 2. Vertical Location of Reactor Vessel Specimen Capsules

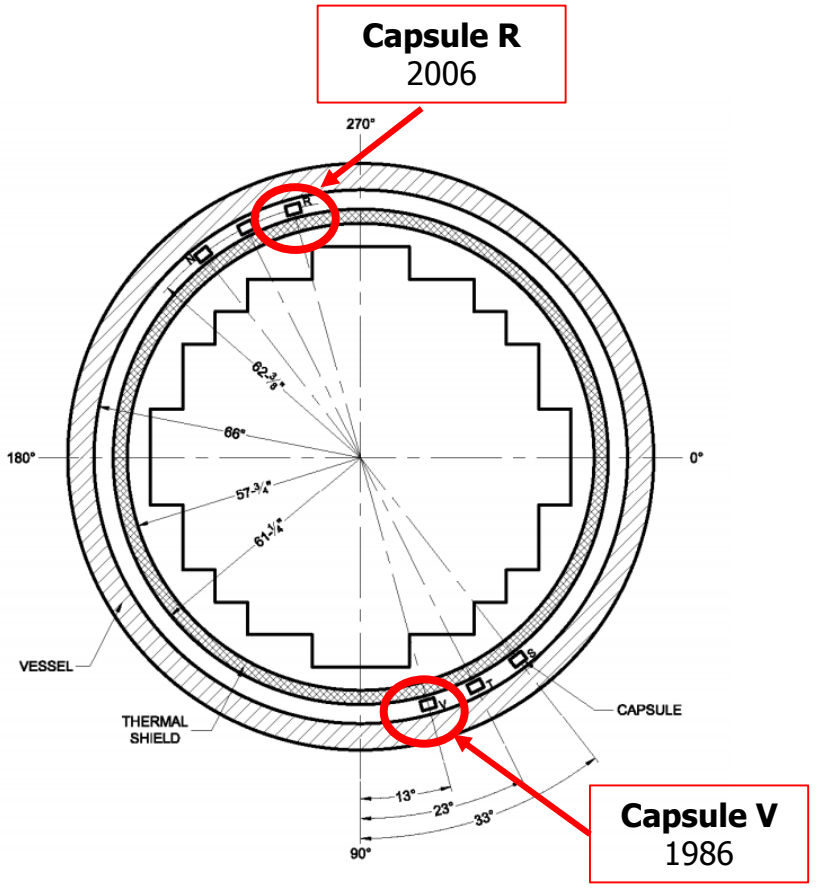

Figure 3. Radial Localization of Reactor Vessel Specimen Capsules.

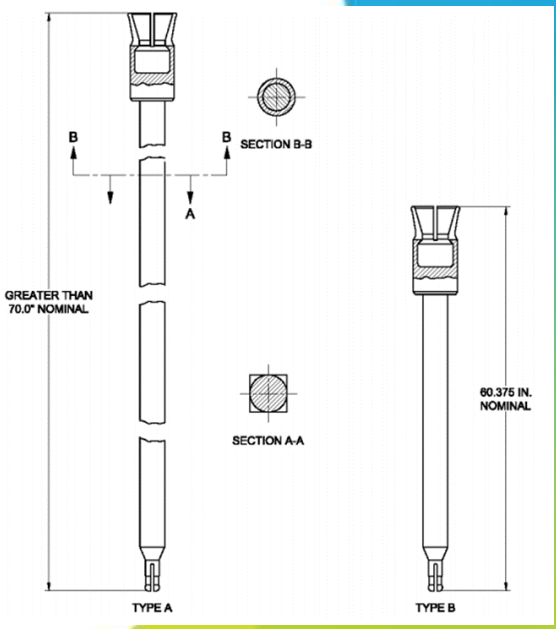

Figure 4. Reactor Specimen Capsule.

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1. Introduction

- The capsules contain:
  - 12 Charpy-V-Notch specimens of axial and tangential forging material, weld and heat affected zone;
  - 3 specimens for tensile testing of axial and tangential forging material and welds.

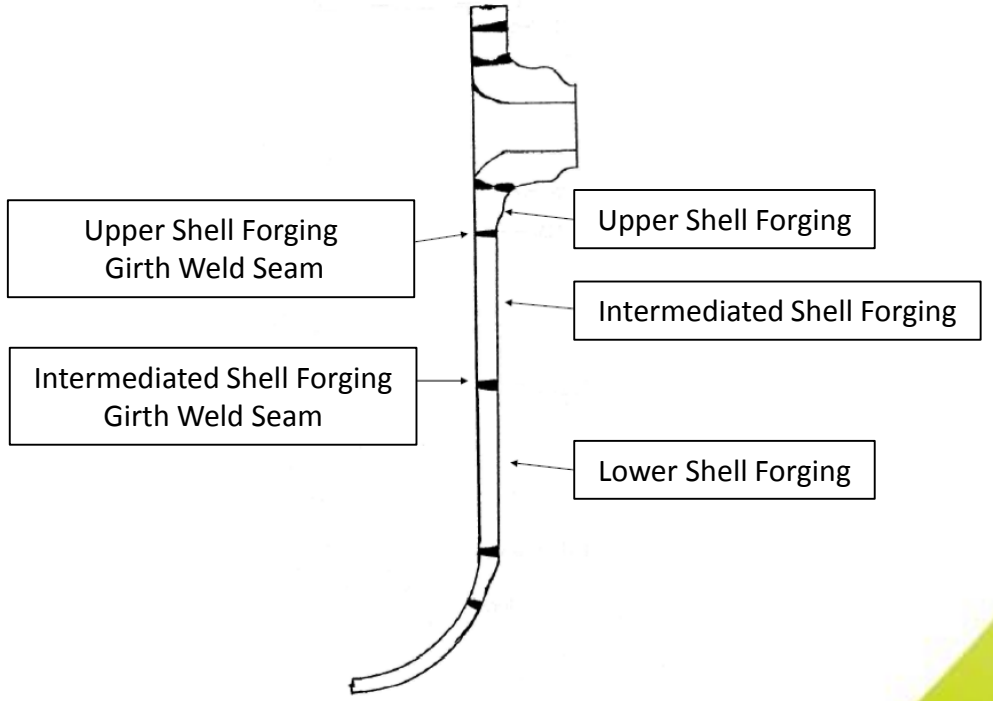

Figure 5. RPV Material Identification for Angra Unit 1.

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1. Introduction

- Results of surveillance capsule testing are used to follow the changes in the material characteristics induced by the radiation throughout the operating life of the Angra 1 pressure vessel.

- Yield strength
- Lateral expansion
- Energy absorbed during impact
- Transition temperature (nil-ductily)
- Appearance of the fracture (ductile or brittle)

2. Reactor Vessel Material Surveillance Program

Yield strength

- Yield strength or yield stress is the material property defined as the stress at which a material begins to deform plastically whereas yield point is the point where nonlinear (elastic + plastic) deformation begins

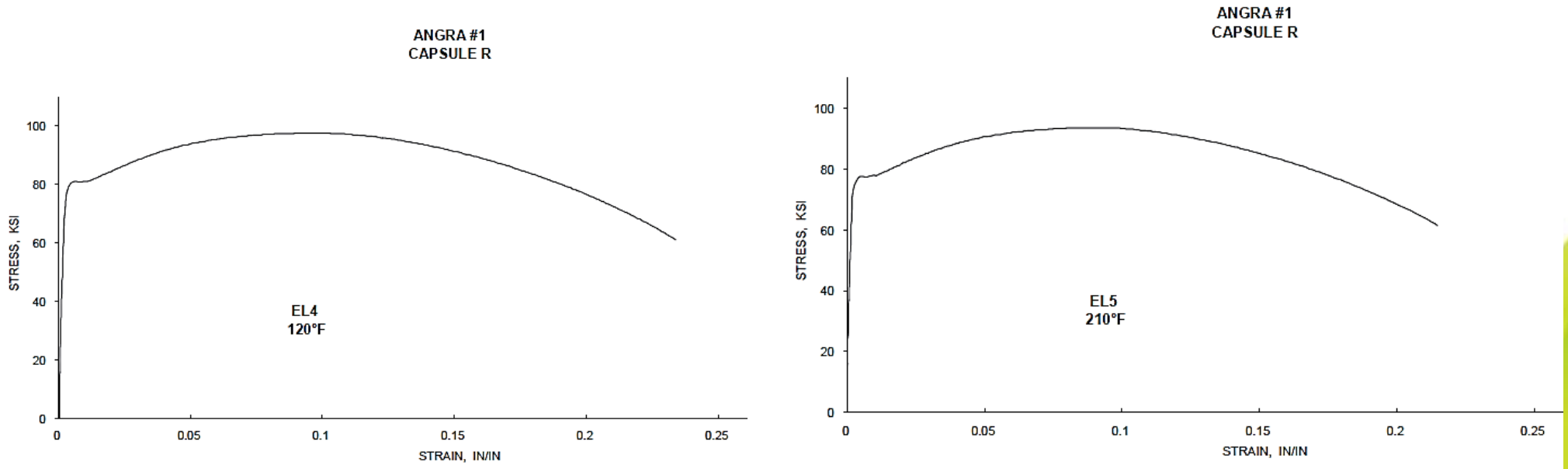
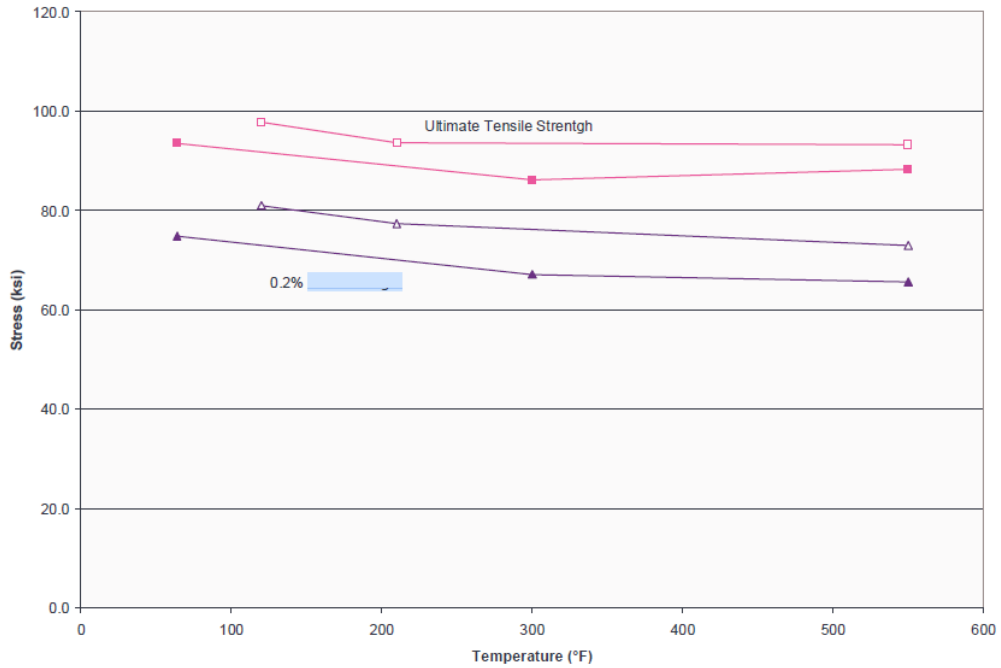


Figure 6. Engineering Stress-Strain Curves for Angra Dos Reis Unit 1 Lower Shell Forging ANH161 Tensile Specimens EL-4 and EL-5 (Tangential Orientation)

2. Reactor Vessel Material Surveillance Program

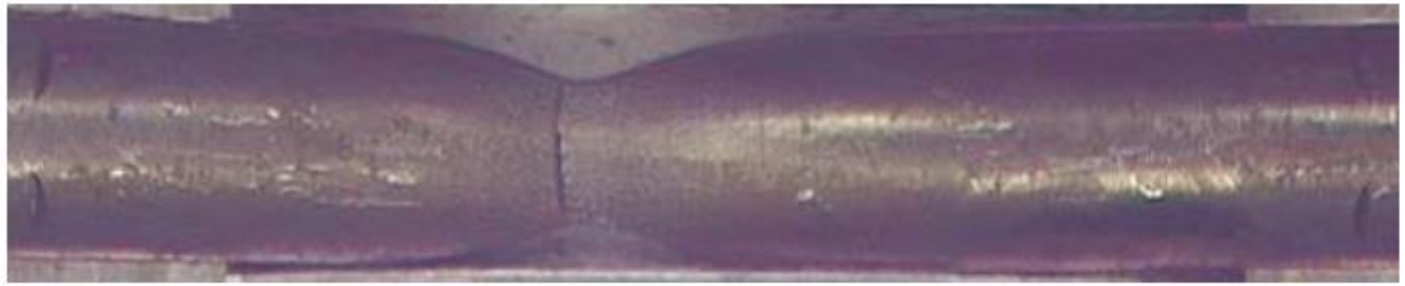
Yield strength



Legend: ▲and ● and ■ are unirradiated
Λ and ○ and □ are irradiated to 4.219E+19 n/cm^2 (E > 1.0 MeV)

Figure 6. Engineering Stress-Strain Curves for Angra Dos Reis Unit 1 Lower Shell Forging ANH161 Tensile Specimens EL-4 and EL-5 (Tangential Orientation)

2. Reactor Vessel Material Surveillance Program



Specimen EL4 – Tested at 49°C

Specimen EL4 – Tested at 98°C

Figure 7. Fractured Tensile Specimens from Angra Dos Reis Unit 1 Reactor Vessel Lower Shell Forging ANH161 (Tangential Orientation)

2. Reactor Vessel Material Surveillance Program

Lateral expansion

- Amount of expansion on each side of fractured specimen. The two halves of the fractured specimen should be measured. This is the equation to measure the lateral expansion:

$$\frac{W_f - W_i}{W_i}$$

W_i – *initial thickness*
W_f – *final thickness*

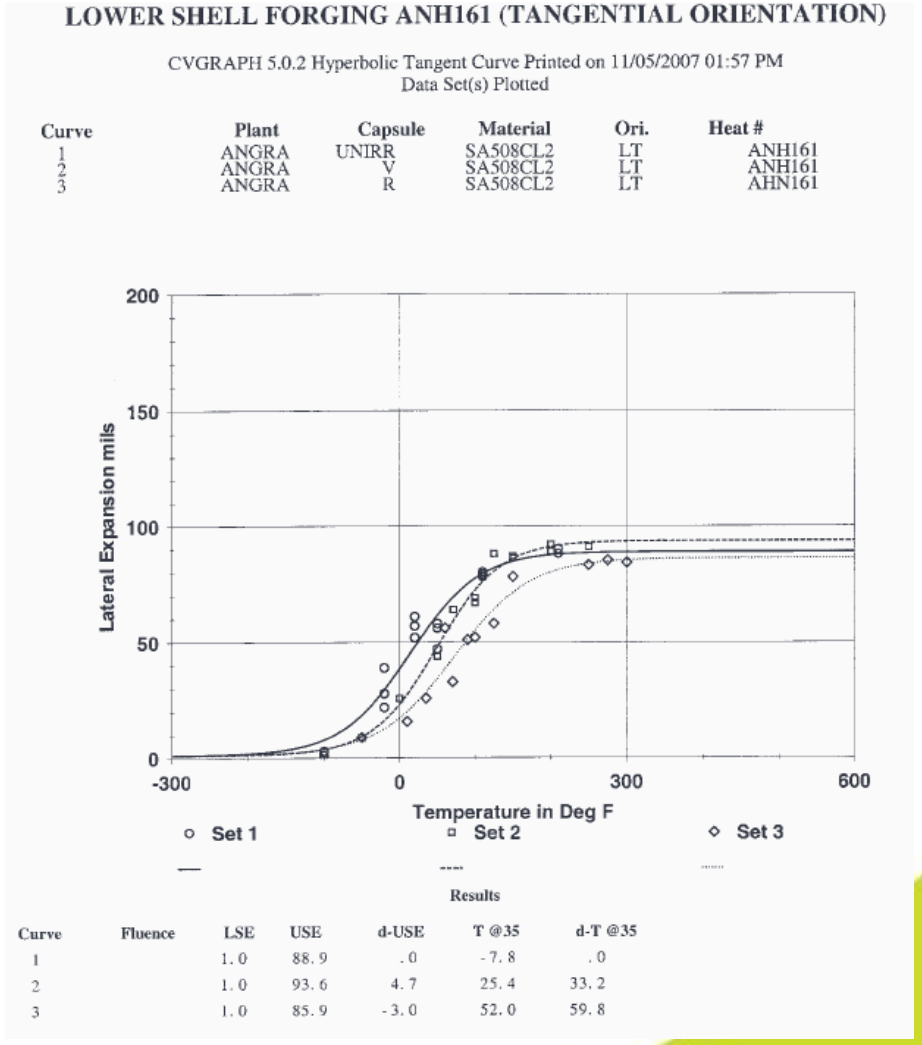


Figure 8. Charpy V-Notch Lateral Expansion vs. Temperature for Angra Dos Reis Unit 1 Reactor Vessel Lower Shell Forging ANH161 (Tangential Orientation)

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Energy absorbed during impact

- Measured directly by the machine. The higher the energy absorbed by the material the greater its toughness. Energy absorbed on impact corresponds to the difference between the potential energy of the pendulum at the height of fall and the potential energy of the pendulum at the height of rebound given by:

$$E_{impact} = M.g.(Hq - hr)$$

$M - pendulum\ mass$

$g - gravity$

$(Hq - hr) - height\ variation$

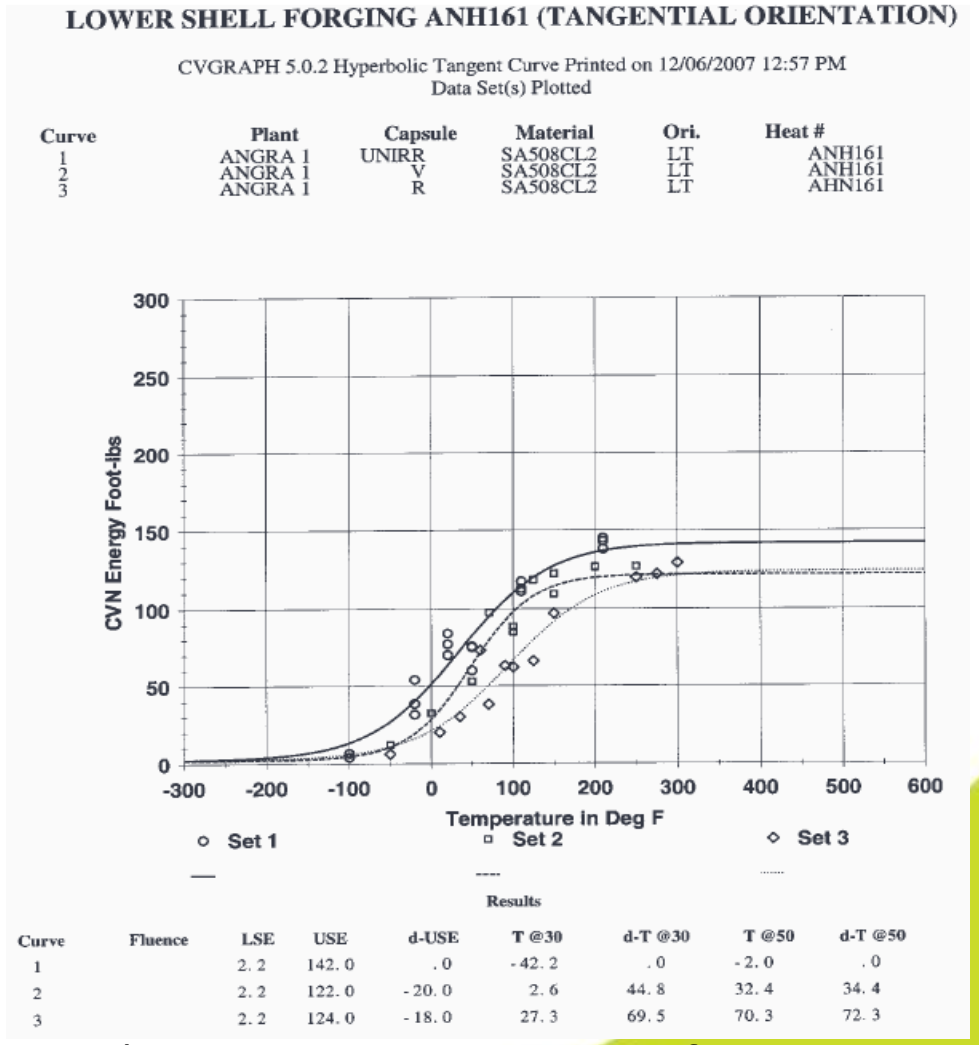

Figure 10. Charpy V-Notch Impact Energy vs. Temperature for Angra Dos Reis Unit 1 Reactor Vessel Lower Shell Forging ANH161 (Tangential Orientation).

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Transition temperature (nil-ductily)

- For each specific metal, there is a critical temperature below which the fracture is fragile. The transition field defines the transition from ductile to fragile behavior. The transition temperature, in simple terms, is the temperature below which the fracture of the material is fragile.

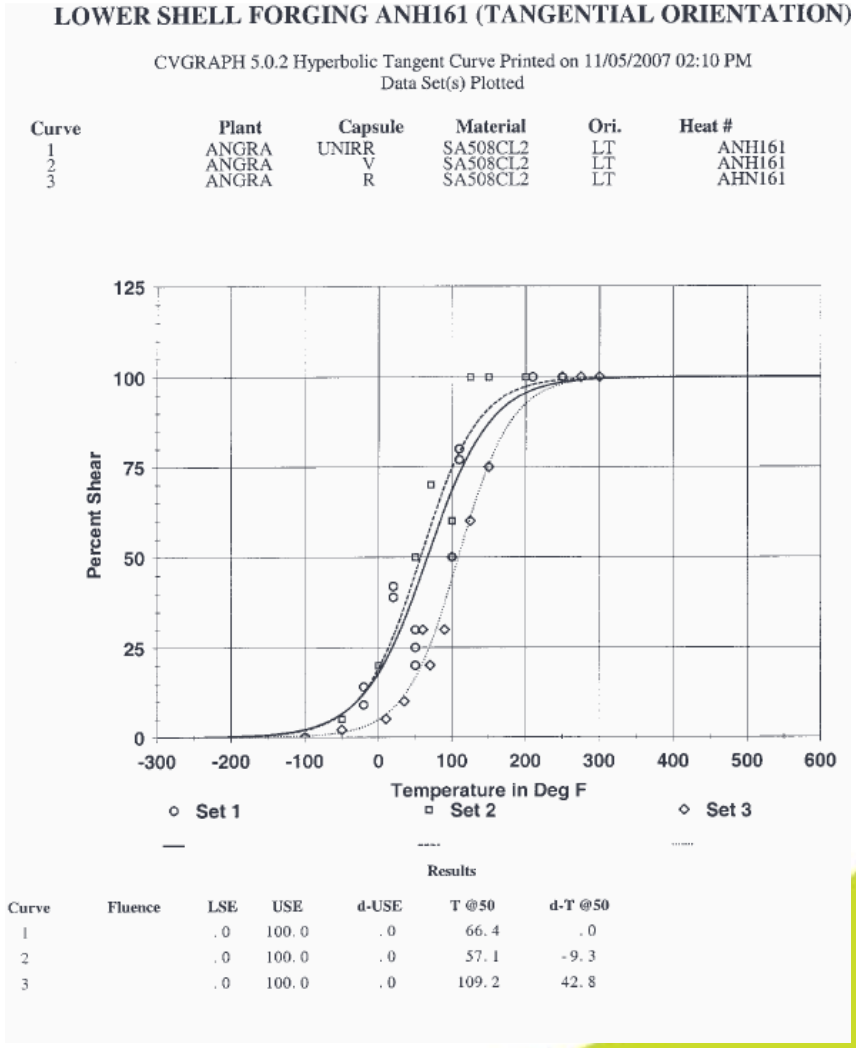
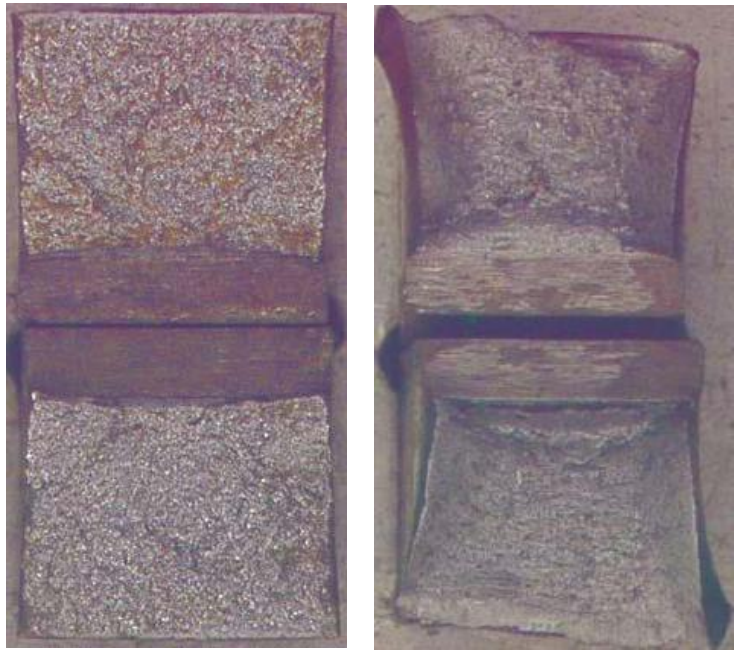


Figure 11. Charpy V-Notch Percent Shear vs. Temperature for Angra Dos Reis Unit 1 Reactor Vessel Lower Shell Forging ANH161 (Tangential Orientation)

2. Reactor Vessel Material Surveillance Program

Appearance of the fracture (ductile or brittle)

- Impact fractures can be fragile or ductile. Fragile fractures are characterized by their crystalline appearance and ductile fractures have a fibrous appearance.



EL18, -12°C EL23, 149°C

Figure 12. Charpy Impact Specimen Fracture Surfaces for Angra Dos Reis Unit 1 Reactor Vessel Lower Shell Forging ANH161 (Tangential Orientation)

2. Reactor Vessel Material Surveillance Program

- Table 2, WCAP-17704-NP [2] presents the results of the tests on specimens, and demonstrates that monitored values met the limits, considering the period of extended operation.

Table 2. Angra Unit 1 Surveillance Capsule Withdrawal Summary

Capsule	Lead Factor	Withdrawal EFPY	Withdrawal Year	Report
V	2.91	0.96	1988	Southwest Research Institute Report, Reactor Vessel Material Surveillance Program for Angra 1: Analysis Capsule V, June 1988.
R	3.04	9.61	2006	WCAP-16875-NP, Analysis of Capsule R from the Angra Dos Reis Unit No. 1 Reactor Vessel Radiation Surveillance Program, Rev. 0, March 2008.
T	1.94	26.1	-	-
P	1.94	<60	-	-
S N	1.83	<80	-	-

* TLAA - WCAP-17704-NP, "Time Limited Aging Analysis on Reactor Vessel Integrity," May 2013.

Fonte: [2]

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2. Reactor Vessel Material Surveillance Program

- With consideration of a 20-year license extension at Angra Unit 1, it is recommended that Capsule T be withdrawn and tested at one times the peak 60-year (54 EOLE) vessel fluence value which corresponds to 25.1 EFPY.

2. Reactor Vessel Material Surveillance Program

- The analysis methodologies used to calculate the fluence and evaluate its effect in the Angra 1 RPV satisfy the requirements:
  - NRC RG 1.190 (Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence) [3];
  - NRC RG 1.99 (Radiation Embrittlement of Reactor Vessel Materials) [4].

3. Conclusions

- The ductile-brittle transition temperature and the drop in the Charpy upper shelf energy values met the limits, considering the period of extended operation;
- Acceptance criteria for the projected reference temperature for pressurized thermal shock and the energy in the upper level of the Charpy curve are in conformity with the period of extended operation (54 EFPY).

3. Conclusions

- The four remaining surveillance capsules are sufficient for obtaining fluence and material properties necessaries to cover the original design life (40 years), the period of extended operation (60 years) and subsequent life extension (80 years) ;
- The analysis methodologies used to calculate the fluence and evaluate its effect in the Angra 1 reactor pressure vessel satisfy the requirements set forth in NRC RG 1.190 and NRC RG 1.99.

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3. Conclusions

- Finally, the reactor vessel material surveillance program ensures that the Angra 1 reactor pressure vessel could continue to meet regulatory and operational requirements over a license extension to 60 years of service and for a potential second 20-year license extension to 80 years of plant operation.

4. Ackmowledgments

- We would like to thank Eletrobras Termonuclear S.A. – ELETRONUCLEAR for giving us the opportunity and for providing us with a workspace and access to all the resources necessary to conduct this work.

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REFERENCES

[1] United States of America, Code of Federal Regulations, 10 CFR 50, Appendix H, "Reactor Vessel Material Surveillance Program Requirements," U.S. Nuclear Regulatory Commission, Washington, D.C., Federal Register, Volume 60, No. 243, dated December 19, 1995.

[2] Westinghouse, WCAP-17704-NP, "Time Limited Aging Analysis on Reactor Vessel Integrity," May 2013.

[3] U.S. NRC Regulatory Guide 1.190, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence," March 2001.

[4] U.S. NRC, Regulatory Guide 1.99, "Radiation Embrittlement of Reactor Vessel Materials," Revision 2, May 1988.