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TECHNOLOGIES INC.

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Ms. Belkys Sosa
ACR Project Manager
US NRC – M/S 0-4D9A
11555 Rockville Pike
Rockville, MD 20852-2738
U.S.A.

Dear Ms. Sosa,

Re: **Selected CSA Standards Covering CANDU Technology Specific Requirements**

In support of NRC's pre-application review of the ACR, specifically focus topics # 1 (Class 1 pressure boundary design) and # 8 (On-power fueling) please find enclosed 3 copies each of the following Canadian Standards Association nuclear standards:

- N285.2-99, "Requirements for Class 1C, 2C, and 3C Pressure-Retaining Components and Supports in CANDU Nuclear Power Plants", May 1999, including its Update No. 2 of November 2000;
- N285.4-94, "Periodic Inspection of CANDU Nuclear Power Plant Components", December 1994;
- N-285.6 Series-88, "Material Standards for Reactor Components for CANDU Nuclear Power Plants", March 1998, Reaffirmed in 2000.

These standards include specific requirements for CANDU technology components, e.g., pressure tubes, rolled joints, end fittings, channel closure components, fuel handling equipment.

If you have any questions with regards this letter and/or the enclosed material please contact the undersigned at (905) 823-9060 extension 6543.

Sincerely,

Vince Langman

Vince J. Langman
ACR Licensing Manager

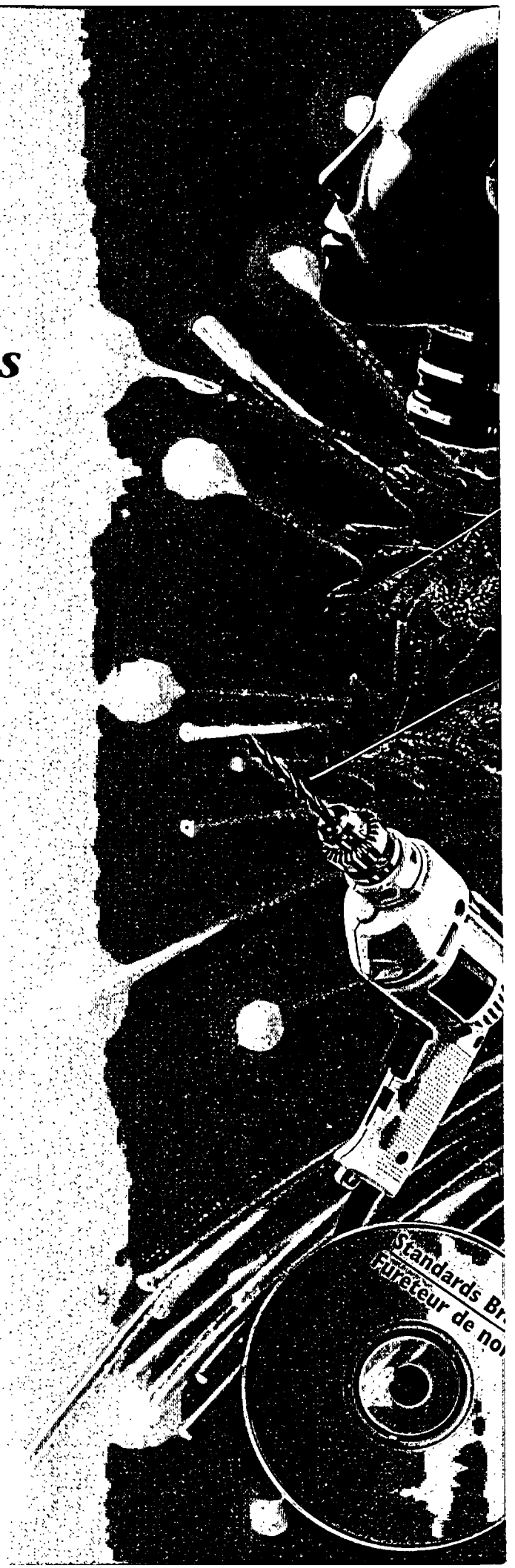
/Enclosures
1. Three copies each of the CSA standards specified in the above letter.

D070

481 North Frederick Avenue, Suite 405, Gaithersburg, MD, 20877 U.S.A., Tel. 301-228-8240, Fax. 301-417-0746

N285.2-99

Requirements for Class 1C, 2C, and 3C Pressure-Retaining Components and Supports in CANDU Nuclear Power Plants



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Preface

This is the second edition of CSA Standard N285.2, *Requirements for Class 1C, 2C, and 3C Pressure-Retaining Components and Supports in CANDU Nuclear Power Plants.* It supersedes the previous edition, published in January 1989. This Standard is part of the N285 series, which provides uniform rules for the design, fabrication, installation, and inspection of CANDU nuclear power plant pressure-retaining systems, components, and supports.

The specific objective of this Standard is to establish rules for the design, fabrication, examination, testing, and inspection of components that have been classified by CSA Standard N285.0 as Class 1C, 2C, or 3C. The rules complement those specified in CSA Standard N285.0 and the *ASME Boiler and Pressure Vessel Code.*

This Standard, therefore, is intended to be used in conjunction with CSA Standard N285.0, and in the event of a conflict between the two Standards, the requirements of this Standard govern.

Users of this Standard are reminded that the design, fabrication, installation, commissioning, and operation of nuclear facilities in Canada are subject to the provisions of the Atomic Energy Control Act and Regulations. Thus, requirements additional to those specified in this Standard may be imposed by the Atomic Energy Control Board.

Pressure-containing systems are also subject to provincial Boiler and Pressure Vessel Acts.

This Standard was prepared by the Subcommittee on Pressure-Retaining Systems and Components for Nuclear Power plants under the jurisdiction of the Technical Committee on CANDU Nuclear Power Plant Systems and Components and the Strategic Steering Committee on Nuclear Standards and was formally approved by the Technical Committee. It will be submitted to the Standards Council of Canada for approval as a National Standard of Canada.

May 1999

Notes:

(1) *Use of the singular does not exclude the plural (and vice versa) when the sense allows.*

(2) *Although the intended primary application of this Standard is stated in its Scope, it is important to note that it remains the responsibility of the users of the Standard to judge its suitability for their particular purpose.*

(3) *This publication was developed by consensus, which is defined by* CSA Policy governing standardization — Code of good practice for standardization *as "substantial agreement. Consensus implies much more than a simple majority, but not necessarily unanimity". It is consistent with this definition that a member may be included in the Technical Committee list and yet not be in full agreement with all clauses of this publication.*

(4) *CSA Standards are subject to periodic review, and suggestions for their improvement will be referred to the appropriate committee.*

(5) *All enquiries regarding this Standard, including requests for interpretation, should be addressed to CSA International, Standards Development, 178 Rexdale Boulevard, Toronto, Ontario M9W 1R3.*

Requests for interpretation should

(a) define the problem, making reference to the specific clause, and, where appropriate, include an illustrative sketch;

(b) provide an explanation of circumstances surrounding the actual field condition; and

(c) be phrased where possible to permit a specific "yes" or "no" answer.

Committee interpretations are processed in accordance with the CSA Directives and guidelines governing standardization *and are published in CSA's periodical* Info Update. *For subscription details, write to CSA Sales Promotion,* Info Update, *at the address given above.*

N285.2-99

Requirements for Class 1C, 2C, and 3C Pressure-Retaining Components and Supports in CANDU Nuclear Power Plants

0. Introduction

This introduction outlines the philosophy and background information that have guided the development of this Standard. It is included to provide guidance and to improve understanding of the Standard, and should not be used to justify deviation from the rules of this Standard.

It is recognized that the *ASME Boiler and Pressure Vessel Code* constitutes a valuable set of requirements for nuclear plant construction; however, although intended to be general, the ASME rules basically address a pressure vessel reactor such as the PWR or BWR type rather than a pressure tube reactor such as CANDU. Modification of the ASME rules as well as additional rules are therefore required to address both the administrative system and the design concepts, which are uniquely Canadian. CSA Standard N285.0 provides general requirements, most of which govern the Canadian administrative system of Classification, Registration, and Quality Assurance, where they differ from *ASME Boiler and Pressure Vessel Code*, Section 3, Subsection NCA.

This Standard provides technical rules to complement those of ASME Code, Section 3. In some cases, ASME Code requirements are modified to properly relate the construction of specific CANDU components to the intent of the ASME Code. In other cases, additional rules are provided when the ASME Code does not address Canadian needs.

Class 1C covers components for installation in Class 1 systems that meet Class 1 requirements as complemented by the rules of this Standard. Similarly, Class 2C and Class 3C cover components for Classes 2 and 3 systems, respectively.

Considerable attention was given to defining the criteria to be used in deciding whether a particular component should be included in this Standard. The criteria that were adopted state that the purpose of this Standard is to provide rules for the pressure-retaining components of CANDU nuclear power plants where, because of the design concept, the rules of the *ASME Boiler and Pressure Vessel Code*, as required by CSA Standard N285.0,

(a) do not exist; or
(b) are not applicable; or
(c) are not sufficient.

An adaptation of this definition is included in N285.0, Clause 5.7.

Several components proposed for inclusion in this Standard fell into the category of upgraded components for use in a system of a higher classification than that for which the component was designed and manufactured. Although the need for upgrading was evident in some circumstances, no consensus could be reached on a generic set of rules to be followed. Each case must, therefore, be specifically proposed to the appropriate provincial regulatory authority for a special registration or other resolution.

At one time it was intended that the use of materials other than those permitted by the *ASME Boiler and Pressure Vessel Code* would be covered in this Standard. The decision was taken to cover such materials

in a separate Standard, CSA Standard CAN/CSA-N285.6. The use of non-ASME Code material is, therefore, no longer considered to be a valid reason for including the component in this Standard. In addition to the material specification, CSA Standard CAN/CSA-N285.6 contains the allowable stresses and other relevant design information for these materials.

It was decided that this Standard should provide rules for elastomeric components, where the consequence of their failure is a significant release of fluid. Items such as hoses are addressed, but seal components such as O-rings and gaskets, the failure of which results in a leak rather than rupture, are not covered.

Fuelling machine supports are addressed in this Standard. Portions of them have a mobility not usually found in supports for pressure-retaining components. As an example, an elevating bridge and carriage is commonly used to move a fuelling machine from one reactor channel to another for on-power fuelling. A mechanism such as a ball screw and nut assembly is often used to produce bridge and carriage motion and to provide support. Rules in this Standard primarily cover the construction of these mechanisms and the control and interlock requirements necessary to prevent overstressing of the pressure boundary, or its support, caused by inappropriate support movement. Reference is made to the ASME Code, Section 3, Subsection NF, for structural support elements.

Instruments and instrument lines are not addressed since they are covered by CSA Standard N285.0.

This Standard does not deal with concrete pressure-retaining components such as a calandria vault. Suitable coverage will be provided in a Standard on safety-related concrete structures, CSA Standard CAN/CSA-N291.

This Standard deals with components for Class 1, 2, and 3 systems. Components for Class 4 systems are addressed in CSA Standard CAN/CSA-N285.3.

1. Scope

1.1

This Standard applies to pressure-retaining components and their supports of CANDU nuclear power plants that have a Code Classification of Class 1C, 2C, or 3C as defined by CSA Standard N285.0.

1.2

This Standard provides rules that complement those in CSA Standard N285.0 for the design, fabrication, installation, examination, and inspection of CANDU nuclear power plant components and supports.

1.3

This Standard provides rules intended to ensure the pressure-retaining integrity of components. Its rules do not address operability. Other design requirements are specified in the appropriate contractual documents.

1.4

This Standard provides rules for the support of fuelling machines.

1.5

This Standard applies only to new construction completed prior to the plant being declared in-service. Repairs or modifications to be made after the plant has been declared in-service should be carried out in accordance with CSA Standard N285.0.

1.6
This Standard does not provide requirements for temporary loads, such as those generated by freeze plugs or other devices used during maintenance operations.

1.7
The values given in SI (metric) units are the standard. The values given in parentheses are for information only.

2. Definitions, Reference Publications, and Abbreviations

2.1 Definitions
In addition to the definitions listed in CSA Standard N285.0, the following definitions apply in this Standard:

Calandria – a cylindrical vessel containing the moderator, closed at both ends by end shields.

Calandria assembly – a multicompartment vessel consisting of a calandria, end shields, and calandria tubes.

Calandria tube – a tube spanning the calandria, separating the fuel channel from the moderator.

Calandria tubesheet – a plate forming part of the end shield that is the common boundary between the calandria and the end shield.

Channel closure safety lock – a device that prevents the accidental or unintentional disengagement of the fuel channel closure.

End fitting – an extension to the pressure tube that provides for connection to the heat transport system and access for refuelling.

End shield – a vessel consisting of a shell and two tubesheets interconnected by lattice tubes, filled with radiation-shielding material.

Fuel channel – an assembly of a pressure tube with end fittings.

Fuel-handling equipment – the equipment used to refuel a reactor and transfer irradiated fuel to the storage bay.

Fuelling machine – a machine used to load new fuel into and remove irradiated fuel from a fuel channel.

Fuelling machine supports – supports that transmit the loads from the fuelling machine pressure-retaining components to the building structure.

Fuelling tubesheet – a plate forming part of the end shield that faces the fuelling machine.

Lattice tube – a cylindrical component joining calandria and fuelling tubesheets, with provision to locate and support an end fitting.

Liquid injection nozzle – a tube spanning the calandria, with holes for discharging neutron-absorbing liquid into the moderator.

Pressure tube – part of the fuel channel assembly located within the calandria tube and designed to contain nuclear fuel and coolant.

Reactivity control units – devices designed to measure and control the neutron flux in a nuclear reactor.

Reinforced elastomeric hoses – flexible conduits formed of elastomers reinforced with braiding or spiral windings, used to convey pressurized fluids.

2.2 Reference Publications

This Standard refers to the following publications and where such reference is made it shall be to the edition listed below.

Note: *New or amended editions of these referenced publications may exist. The user may find it more appropriate to refer to such editions.*

CSA Standards

N285.0-95,
General Requirements for Pressure-Retaining Systems and Components in CANDU Nuclear Power Plants;

CAN/CSA-N285.3-88 (R1994),
Requirements for Containment Systems Components in CANDU Nuclear Power Plants;

CAN/CSA-N285.6 Series-88 (R1994),
Material Standards for Reactor Components for CANDU Nuclear Power Plants;

N291, *Under development,*
Requirements for Safety-Related Structures for CANDU Nuclear Power Plants.

ASME* Boiler and Pressure Vessel Code, 1995

Section 2, Part A, SA-578/SA-578M,
Material Specifications, Ferrous, Specification for Straight-Beam Ultrasonic Examination of Plain and Clad Steel Plates for Special Applications;

Section 2, Part D, Appendix 1,
Basis for Establishing Stress Values in Tables 1A and 1B;

Section 3, Division 1,
Rules for the Construction of Nuclear Power Plant Components:

Section 3A — Subsection NCA, *General Requirements for Divisions 1 and 2;*

Section 3B — Subsection NB, *Class 1 Components;*

Section 3C — Subsection NC, *Class 2 Components;*

Section 3D — Subsection ND, *Class 3 Components;*

Section 3F — Subsection NF, *Supports;*

Appendix 3,
Basis for Establishing Design Stress Intensity Values and Allowable Stress Values;

Appendix 3-2000,
Fatigue Strength Criteria for All Materials;

Section 5,
Nondestructive Examination;

Section 9,
Qualification Standard for Welding and Brazing Procedures, Welders, Braziers, and Welding and Brazing Operators.

ASTM† Standard
D 380-94,
Standard Test Methods for Rubber Hose.

SAE‡ Standards
AS1933-98,
Age Controls for Hose Containing Age-Sensitive Elastomeric Material;

J343-90,
Tests and Procedures for SAE 100R Series Hydraulic Hose and Hose Assemblies;

J1926 Standards — *Connections for General Use and Fluid Power-Ports and Stud Ends with ISO 725 Threads and O-ring Sealing:*
Part 1 (1993) — *Threaded Port with O-ring Seal in Truncated Housing;*
Part 2 (1995) — *Heavy-Duty (S Series) Stud Ends;*
Part 3 (1993) — *Light-Duty (L Series) Stud Ends.*

**American Society of Mechanical Engineers.*
†American Society for Testing and Materials.
‡Society of Automotive Engineers.

2.3 Abbreviations

The following abbreviations apply in this Standard:

AISI	American Iron and Steel Institute
AMS	Aerospace Material Specification
ASM	American Society for Metals
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CSA	Canadian Standards Association
SAE	Society of Automotive Engineers

3. General Requirements

3.1

The following requirements of CSA Standard N285.0 apply, except as otherwise specified, in this Standard:

(a) general requirements in accordance with Clause 3 of CSA Standard N285.0;
(b) responsibilities of the parties in accordance with Clause 4 of CSA Standard N285.0;
(c) classification of components in accordance with Clause 5 of CSA Standard N285.0;
(d) registration of components in accordance with Clause 6 of CSA Standard N285.0;
(e) design of components in accordance with Clause 7 of CSA Standard N285.0;
(f) choice of materials in accordance with Clause 8.1.1 of CSA Standard N285.0 for Class 1C components, Clause 8.1.2 for Class 2C components, and Clause 8.1.3 for Class 3C components;

(g) fabrication and installation in accordance with Clause 9 of CSA Standard N285.0;
(h) quality assurance in accordance with Clause 10 of CSA Standard N285.0;
(i) inspection, examination, and testing in accordance with Clause 11 of CSA Standard N285.0;
(j) certification and overpressure protection in accordance with Clause 12 of CSA Standard N285.0;
(k) in-service requirements in accordance with Clause 13 of CSA Standard N285.0; and
(l) supports in accordance with Clause 14 of CSA Standard N285.0.

Note: *CSA Standard N285.0 directs the user to the relevant paragraphs or clauses of the* ASME Boiler and Pressure Vessel Code *and to other CSA Standards.*

3.2
Where a reference is made to another Clause in this Standard, all of its subsidiary Clauses shall apply.

4. Specific Requirements
Class 1C, 2C, and 3C components shall comply with the design, fabrication, inspection, examination, test, and installation requirements of CSA Standard N285.0 for the class of system in which they are to be installed, except as otherwise required by this Standard.

Note: *CSA Standard N285.0 directs the user to the relevant paragraphs or clauses of the* ASME Boiler and Pressure Vessel Code *and to other CSA Standards.*

5. Fuel Channel Assemblies

5.1 General
With the exceptions specified below, the fuel channel pressure boundary components shall be constructed to meet the Class 1 requirements of CSA Standard N285.0, which specifies the relevant clauses of the *ASME Boiler and Pressure Vessel Code.*

5.2 Pressure Tube to End-Fitting Joints

5.2.1
The requirements of Clause 8 shall be met, except that both Clauses 8.1(c)(i) and (c)(ii) shall apply.

5.2.2
For mechanical joints made by roll expansion, the load required to pull the pressure tube out of the end fitting shall be measured on at least four prototype joints. This pullout load shall exceed three times the design condition axial load, including pressure, when the test is performed at design temperature, or four times if the test is at ambient conditions.

5.2.3
The reduction in wall thickness required to produce joints of adequate strength shall be determined during the prototype tests.

5.3 Pressure Tubes

5.3.1 Material

5.3.1.1
The material for pressure tubes shall be selected from CSA Standard CAN/CSA-N285.6.1.

5.3.1.2
The material properties listed in CSA Standard CAN/CSA-N285.6.7 shall be used in design calculations and shall be supplemented by the following:
(a) the effects of irradiation enhancement of material properties may be included if supported by testing and if incorporated in allowable values using the factors of conservatism given in the rules of the *ASME Boiler and Pressure Vessel Code,* Section 3, Division 1, Appendices 3 and 3-2000;
(b) the effect on ductility and resistance to fatigue shall be used in the design calculations; and
(c) irradiated fatigue curves shall be constructed using the criteria in the *ASME Boiler and Pressure Vessel Code,* Section 3, Division 1, Appendices 3 and 3-2000.

5.3.2 Design

5.3.2.1
The requirements of CSA Standard N285.0, Clause 7, shall apply.

5.3.2.2
The minimum wall thickness assumed in the analyses shall include allowances for internal and external corrosion, thinning due to diametral and axial creep, and wear from fuel movement.

5.3.2.3
Pressure tubes made from zirconium alloys shall be protected against delayed hydride cracking by ensuring that the maximum tensile stress, under design level A (normal) and level B (upset) conditions, plus the maximum initial residual tensile stress, shall at no time exceed 67% of the tensile stress required to initiate delayed hydride cracking as determined in the laboratory by tests on unnotched specimens.

5.3.2.4
Pressure tube material shall be capable of sustaining a subcritical through-wall crack (ie, leak before breaking).

5.3.2.5
A system capable of detecting leaks before through-wall cracks grow to unstable lengths shall be provided.

5.3.2.6
The design and stress analyses shall include the effects of creep deformation. This includes axial creep, diametral creep, and creep-sag of the pressure tubes.

5.3.3 Support

5.3.3.1
Pressure tubes shall be supported such that they will not contact the calandria tube during the life of the channel.

5.3.3.2
The effects of calandria tube sag in relation to other core components shall be considered in the design.

5.3.3.3
Devices used to maintain pressure tube and calandria tube separation shall be shown to be metallurgically compatible with the materials they contact. Such devices shall be designed to remain in their design location for the lifetime of the plant.

5.4 Channel Closure

5.4.1
The channel closures installed on a CANDU reactor shall be locked in place by closure safety locks in accordance with Clause 9.2.

5.4.2
The closure body shall close off the end-fitting bore so that any failure of the seal disc does not result in a loss of coolant in excess of the capacity of the make-up system.

5.4.3
The components of the channel closure that support the flexible seal disc shall be designed, manufactured, and tested to the requirements of Class 1 pressure-retaining components.

5.4.4
Channel closures shall be tested for leakage each time they are installed and prior to removal of the fuelling machine.

5.4.5
The channel closure components shall be designed so that the effects of partial engagement or misalignment do not lead to progressive distortion or failure of the pressure boundary.
Note: *Flexible seal discs act as self-energizing gaskets that flex during installation, operation, and removal.*

6. Calandria Assembly

6.1 Calandria Tube to Tubesheet Rolled Joint

6.1.1
The rules given in Section 3, paragraph ND-3671.2, of the *ASME Boiler and Pressure Vessel Code* shall be used for the design of the calandria tube to tubesheet joint where the calandria is to be registered as a Class 3C component.

6.1.2
The rules given in Section 3, paragraph NC-3671.2, of the *ASME Boiler and Pressure Vessel Code* shall be used for the design of the calandria tube to tubesheet joint where the calandria is to be registered as a Class 2C component and designed to the rules of paragraph NC-3300.

6.1.3
The requirements of Clause 8 of this Standard shall apply to the calandria tube to tubesheet joint where the calandria is to be registered as a Class 1C component, or a Class 2C component designed to the rules of Section 3, paragraph NC-3200, of the *ASME Boiler and Pressure Vessel Code.*

6.2 External Pressure Design of the Calandria Tube

The requirements of CSA Standard N285.0, Clause 7, shall be met, except that in lieu of meeting the requirements of the *ASME Boiler and Pressure Vessel Code*, Section 3, paragraph NC-3133.3, it shall be shown by test or analysis that deformation of the calandria tube onto the pressure tube, due to external pressure under all service conditions, will not cause rupture of the calandria tube.

6.3 Lattice Tube to Calandria Tubesheet Joint

6.3.1

As an alternative to the requirements of Section 3, paragraph NC-4243.2 of the *ASME Boiler and Pressure Vessel Code*, it is permitted to machine hubs onto the calandria tubesheet, provided that the following requirements are met:

(a) tubesheet plate material, after having been rolled to size, heat treated, and descaled, shall be ultrasonically examined over 100% of both sides, in accordance with the requirements of the *ASME Boiler and Pressure Vessel Code*, Section 2, SA-578, and Section 5;

(b) the plates shall be examined by moving the search unit in parallel paths with a 10% minimum overlap; and

(c) a response, at any depth, equal to or greater than that which would be given by a 6.33 mm (0.25 in) diameter flat-bottomed, open-top hole drilled to the same depth shall be cause for rejection and subsequent repair in accordance with the requirements of Section III, paragraph NC-2530, of the *ASME Boiler and Pressure Vessel Code.*

6.3.2

When welding of each lattice tube is complete, the following examinations shall be made:

(a) ultrasonic examination of a 100 mm (3.94 in) wide annulus around each tubesheet bore, in accordance with Clause 6.3.1, except that the examination shall be performed from one side only; and

(b) liquid-penetrant examination of all bores in the calandria tubesheet, in accordance with Section 3, paragraph NC-2546, of the *ASME Boiler and Pressure Vessel Code.*

6.4 Radiography of Lattice Tube to Calandria Tubesheet Welds

6.4.1

As an alternative to the requirements of Section 3, paragraph NC-5254, of the *ASME Boiler and Pressure Vessel Code*, it is permitted to radiograph only a statistical sampling of the lattice tube to calandria tubesheet welded joints, provided that the requirements of Clauses 6.4.2 to 6.4.6 are met.

6.4.2

Only automatic welding (as defined in the *ASME Boiler and Pressure Vessel Code*, Section 9, QW-492) is permitted, except for repair welding. Before commencing production welding, each welding operator shall make three consecutive, acceptable sample joints for each lattice tube to tubesheet joint design, using the geometry, materials, interference fits, procedure, and welding equipment to be used for the production joints. All welds in these sample joints shall be examined in accordance with the requirements for production joints and shall also be fully radiographed.

6.4.3

The lattice tube to calandria tubesheet joints shall be welded in batches. A batch shall consist of a maximum of 10 welded joints made by one welding operator using one automatic welding machine in one day without change in any variable.

6.4.4
The root and final passes of each weld shall be examined by the liquid-penetrant method.

6.4.5
After a welding operator completes a batch of lattice tube to calandria tubesheet welds (see Clause 6.4.3), and before proceeding to the next batch, one joint, selected at random from that batch, shall be 100% radiographed. If the weld is not acceptable, all welds made by that welding operator, after the acceptance weld of the previous batch, shall also be radiographed.

6.4.6
All defective welds shall be repaired, reexamined, and reradiographed.

6.5 Lattice Tube to Fuelling Tubesheet Joint and Alternative Lattice Tube to Calandria Tubesheet Joint
As an alternative to the requirements of Section 3, paragraph NC-3252.4(d), of the *ASME Boiler and Pressure Vessel Code*, partial penetration welds for the lattice tube to tubesheet joint are permitted, provided the following requirements are met:
(a) the joint strength shall be demonstrated by analysis or test to be adequate for imposed service loading;
(b) the tube shall have an interference fit with the tubesheet bore after fabrication is completed; and
(c) the root and final pass of each weld shall be examined by the liquid-penetrant method.

6.6 Lattice Tube Radiography
As an alternative to the requirements of Section 3, paragraph NC-2577.2(a), of the *ASME Boiler and Pressure Vessel Code*, centrifugally cast lattice tubes may be radiographed in a partially machined condition that exceeds 120% of finished thickness prior to installation into the end shields. The penetrameter size shall be based on final machined thickness.

7. Reactivity Control Units

7.1 Control Rod Drive Housings
Control rod drive housings shall meet the requirements of Clause 5 of CSA Standard N285.0. (The requirements of Section 3, paragraph NCA-1271, of the *ASME Boiler and Pressure Vessel Code* are not applicable to CANDU reactors as they are not part of the heat transport system pressure boundary.)

7.2 Liquid Injection Nozzle
The requirements of Clause 8 shall apply to the joint between the injection tube and injection nozzle.

8. Joints Between Tubular Components
Joints, other than welds between metallic tubular components for which requirements are not provided in CSA Standard N285.0, may be used, provided the following requirements are met:
(a) provision shall be made to prevent separation of the joints under all specified service loadings;
(b) the joints shall be accessible for inspection, maintenance and/or removal, and replacement;
(c) either of the following two criteria shall be met:
  (i) prototype joints shall be subjected to performance tests to determine the structural integrity of

the joints under simulated service conditions; all significant design and operating parameters affecting the integrity of the joints shall be included in the qualification tests; or

(ii) joints shall be designed in accordance with the rules of Section 3, paragraph NB-3200, of the *ASME Boiler and Pressure Vessel Code*; and

(d) production joints shall be produced using the same tooling design and procedures that have been qualified in the manufacture of prototype joints; each joint shall be inspected for structural integrity by ensuring that the required parameters determined from the prototypes have been achieved.

9. Fuel-Handling Equipment

9.1 Reinforced Elastomeric Hose Assemblies

9.1.1 General

Elastomeric hose may be used in Class 2 and 3 systems, provided that the requirements of Clause 9.1 are met; however, it should only be used where system function cannot be readily achieved using other acceptable methods.

9.1.2 System Design

9.1.2.1

Elastomeric hose may be used only if a failure will not cause the dose limit for the general public or operating personnel to be exceeded. This may be achieved by combining the hose installation with a reliable quick-acting closing device to stop leakage and to minimize the spread of activity following a hose failure, or by ensuring that personnel are excluded or shielded from the hose operating area and the area is suitable for containing any radioactive fluids lost from the system.

9.1.2.2

The effect of a hose failure on the safe functioning of the process system shall be considered by the process system designer, although operation of the system is beyond the scope of this Standard.

9.1.3 Materials

9.1.3.1

The hose shall be reinforced with either fabric or metal. The materials used shall be compatible with the fluid being conveyed, the service conditions, and the environment.

9.1.3.2

The hose end-fitting material shall conform to CSA Standard N285.0, Clause 8, for the class of the system in which it is installed. Alternatively, the material shall conform to an established material specification (eg, CSA, ASTM, ASME, AMS, SAE, or AISI) as well as supplementary testing for chemical and mechanical properties, etc, such that material properties and a level of control equivalent to that required by ASME are established. The hose assembly manufacturer shall supply documentation for approval by the system designer that specifies all material test requirements and shall furnish a Certificate of Compliance for the materials used.

9.1.4 Design

9.1.4.1
The design of a hose assembly shall be qualified by performing the same tests as required for each production batch of hose, as described in Clause 9.1.5. The tests shall be repeated for each hose size.

9.1.4.2
The hose design specification shall stipulate where additional tests are required to show resistance to oil, ozone, radiation, vacuum, or any substance that may be present and might have a detrimental effect on the life of the hose. Additional tests are not normally required where sufficient knowledge of the material's physical and chemical properties is documented.

9.1.5 Fabrication

9.1.5.1
The fabrication of each hose assembly or bulk hose shall be qualified by performing, as a minimum, the following tests, using the procedures described in ASTM Standard D 380. The results of the tests shall be included in the history docket for the hose assembly. In cases of conflict between the ASTM Standard and the following test requirements, the latter shall govern:
(a) Three sample hose assemblies from each production batch of hose shall be burst tested. The minimum free length of hose in each sample shall be 450 mm (18 in). The pressure shall be increased at a constant rate so as to attain the minimum burst pressure within a period of not less than 15 s nor more than 30 s. There shall be no indication of leakage or hose failure below the required minimum burst pressure of four times the design pressure.
(b) Three sample hose assemblies, with a minimum free length of hose of 300 mm (12 in), from each production batch of hose shall be leak tested as described in SAE Standard J343.
(c) Each hose assembly shall be hydrostatically proof tested to two times its design pressure for a period of not less than 30 s nor more than 60 s. There shall be no indication of leakage or hose failure.
(d) Three sample hose assemblies from each production batch of hose shall be impulse tested as described in SAE Standard J343. Unaged hose assemblies may be used, except where otherwise indicated in the hose design specification. The test fluid circulated through the assemblies shall be at an operating temperature specified in the hose design specification. The assemblies shall withstand the number of cycles specified by the hose design specification without any indication of leakage or hose failure. In the absence of a specified requirement, the assemblies shall withstand a minimum of 100 000 cycles without any indication of leakage or hose failure. The test pressure shall be 125% of the system design pressure.
(e) All hose shall be visually examined for defects and proper identification. In addition, hose assemblies shall be inspected to ensure that the hose end fittings have been properly installed.
(f) Each hose and hose end fitting shall be dimensionally checked in accordance with SAE Standard J343.
(g) Tests to show change in length, flexure, or other such characteristics shall be performed as required by the hose design specification.

9.1.5.2
The hose shall be legibly marked with the manufacturer's name, hose identification number, batch number, and date of manufacture. The markings shall be repeated at intervals not greater than 450 mm (18 in).

9.1.6 Hose Replacement

9.1.6.1
Elastomeric hose assemblies have a finite life. The process system designer, therefore, shall provide a hose replacement schedule for the system operator. An example of a hose replacement schedule is provided in SAE Standard AS1933. The process system designer shall take into consideration the following:
(a) the hose manufacturer's recommendations for installation, operation, and hose replacement;
(b) previous experience with the hose in similar applications;
(c) that hose life can be considerably reduced by flexing the hose to less than the minimum bend radius, twisting the hose, kinking, rubbing, or crushing the hose, and subjecting the hose to high temperature or high pressure surges; and
(d) that reusable hose end fittings have limited remake capabilities.

9.1.6.2
The operator of the process system in which the hose is used shall replace the hose assemblies as recommended by the process system designer until in-service experience indicates that the hose life is other than expected. At that time the hose replacement schedule shall be changed to ensure that all hose assemblies will be replaced before failure.

9.1.6.3
Hoses assembled into hose assemblies by the operator (ie, by attachment of new or existing end fittings to lengths of hose) shall be inspected and pressure tested in accordance with Clause 9.1.5.1(c) and (e) before being used in-service.

9.1.6.4
Elastomeric hose assemblies have a limited shelf life. The process system designer shall specify the storage conditions and shelf life of new and spare hose assemblies in a way similar to that for new hoses (see Clause 9.1.6.1).

9.2 Reactor Fuel Channel Closure Safety Lock

9.2.1 General
For reactor systems in which on-power fuelling is used, a safety lock shall be provided on each channel closure to prevent it from being unintentionally released from a fuel channel.

9.2.2 Materials
The materials used for the safety lock shall conform to an established material specification (eg, CSA, AISI, ASM, ASTM, ASME, or SAE) and shall be determined by the system designer to be adequate for the conditions. A material test report shall be required for the materials used. In addition, for any portion of the safety lock that performs a pressure-retaining or pressure boundary support function, the additional material requirement of the applicable code class shall apply.

9.2.3 Design

9.2.3.1
The safety lock shall be designed within the allowable stress values established by the *ASME Boiler and Pressure Vessel Code*, Section 2, Part D, Appendix 1.

9.2.3.2
The safety lock shall be a positive mechanical locking device. Frictional-type locking devices shall not be permitted.

9.2.4 Examination
The load-carrying members shall be examined by either the magnetic-particle or the liquid-penetrant method in accordance with the *ASME Boiler and Pressure Vessel Code*, Section 5, except for sizes which are normally exempt from such tests in the *ASME Boiler and Pressure Vessel Code*, Section 3, Subsection NB. The acceptance standards those given in the *ASME Boiler and Pressure Vessel Code*, Section 3, paragraphs NB-5340 and NB-5350.

9.3 Fuelling Machine to Channel Coupling Interlocks

9.3.1 General
For reactor systems where on-power fuelling is used, two independent and diverse interlocks shall be provided to prevent uncoupling of a fuelling machine from a reactor fuel channel when the channel closure is removed. The diversity of the interlocks shall not preclude the use of similar pressure-sensing technology for both interlocks. The two interlocks used when the reactor is operating at normal on-power pressures may be different from the two interlocks used at low or shutdown pressures.
Note: *The term "diverse" is used here to mean different in nature (eg, hardwired, software, mechanical interlocks).*

9.3.2 Materials
The materials for a mechanical locking device shall conform to an established material specification (eg, CSA, AISI, SAE, ASME, ASTM, or ASM) and shall be determined by the system designer to be adequate for the conditions. A material test report certifying the chemical and mechanical properties of the material used shall be required. In addition, for any portion of an interlock that performs a pressure-retaining or pressure-retaining support function, the material requirements of CSA Standard N285.0 shall apply.

9.3.3 Design

9.3.3.1
When the fuelling machine is coupled to a reactor fuel channel at normal on-power pressures, one of the two interlocks shall be a positive mechanical locking device that is actuated by reactor pressure while the fuelling machine is open to the fuel channel. At other pressures, a mechanical interlock shall not be required. A locking device that depends on friction shall not be acceptable.

9.3.3.2
The allowable stress values and the method of analysis for pressure-retaining components and their supports in the interlock system shall conform with the requirements for the applicable code class. Other load-carrying members shall be designed using allowable stress values not greater than those in Section 2, Part D, Appendix 1, of the *ASME Boiler and Pressure Vessel Code.*

9.3.3.3
The interlocks shall be engaged prior to removal of the channel closure and shall remain engaged until the channel closure has been inserted and secured. A mechanical connection between the interlocks and the closure securing mechanism shall not be required.

9.3.4 Examination

Pressure-retaining components and their supports in the interlock system shall be examined in accordance with the requirements of CSA Standard N285.0. All accessible surfaces of other load-carrying components shall be examined by either the magnetic-particle or the liquid-penetrant method in accordance with the *ASME Boiler and Pressure Vessel Code*, Section 5. The acceptance standards shall be those given in the *ASME Boiler and Pressure Vessel Code*, Section 3, paragraphs NB-2545, NB-2546, NB-5340, and NB-5350.

9.3.5 Testing

9.3.5.1

To ensure operability, the mechanical locking device shall be tested both during commissioning and after maintenance, which could affect interlock operation. The test shall include a deliberate attempt to unclamp the fuelling machine, using the maximum force available during normal operation. It shall be performed on a test channel at normal on-power pressures and/or shutdown pressures as appropriate.

9.3.5.2

Hardwired and software interlocks shall be tested for proper operation during commissioning and after any changes or repair of interlock components or any changes to the control system interlock logic.

9.4 Fuelling Machine Supports

9.4.1 General

Fuelling machine supports for on-power fuelling systems may include features that provide for mobility of the components of the support assembly. Such support systems are usually composed of structural supporting elements and mechanisms. They shall be acceptable when the requirements of Clauses 9.4.2 to 9.4.5 inclusive are met.

9.4.2 Classification

The code class of a fuelling machine support (Class 1C, 2C, or 3C) shall be determined by the class of service performed by the fuelling machine while the support is providing support.

9.4.3 Structural Supporting Elements

Structural supporting elements shall meet the requirements of Clause 14 of CSA Standard N285.0. Materials specified in CSA Standard CAN/CSA-N285.6 shall be acceptable.

9.4.4 Mechanisms

Mechanisms that produce or control motions and carry support loads, whose failure would result in a loss of support, shall meet the following requirements:

(a) a stress analysis, experimental stress analysis, or load rating, similar to that required in the *ASME Boiler and Pressure Vessel Code*, Section 3, paragraph NF-3140, shall be required to show that the stresses resulting from the applied loadings satisfy the limits of the requirements of paragraphs NF-3200 and NF-3300;

(b) for materials not conforming to the requirements of paragraph NF-2000 of the *ASME Boiler and Pressure Vessel Code*, Section 3, or CSA Standard CAN/CSA-N285.6, allowable stresses shall be based on the rules of the *ASME Boiler and Pressure Vessel Code*, Section 3, Appendix 3, paragraph 3210; and

(c) mechanisms shall be equipped with controls and interlocks to prevent motion of the support that could result in overstressing a pressure-retaining component or its support. Means shall be provided to verify the operation of controls and interlocks.

9.4.5 Documentation

A design specification, a design report, and a product specification for the complete fuelling machine support system shall be provided. The design report shall contain the fuelling machine support stress analysis or load rating, and the mechanism stress analysis required by Clause 9.4.4. In addition, a complete description of the controls and interlocks, installed to prevent overstressing of the pressure boundary or its support, shall be included.

9.5 Fuelling Machine Threaded Process and Instrumentation Connections

Threaded connections to Fuelling Machine Class 1 vessel walls may be used provided they meet the following requirements:

(a) The thread shall be either

(i) a straight thread 1-5/16 in outside diameter or less; or

(ii) a tapered pipe thread NPS 1/2 in or less.

(b) The applicable requirements of paragraph NC-3671.3 of the *ASME Boiler and Pressure Vessel Code,* Section 3, shall be satisfied. Connections using a straight O-ring boss in accordance with the SAE J1926 Standards may be used, providing these have been shown to be suitable for the specified service conditions. The basis for establishing the adequacy of the seal shall be included in the design report. Seal welds shall not be used.

(c) Threaded connections shall be accessible for inspection and maintenance.

(d) The reinforcement in the vessel wall shall be integral with the portion of the vessel penetrated. The dimensions of the reinforcement shall be established in accordance with paragraph NB-3300 of the *ASME Boiler and Pressure Vessel Code,* Section 3. The opening diameter, "d", shall be equal to the major diameter of a straight thread, or the outside pipe diameter for a tapered pipe thread.

(e) All other applicable requirements of Subsection NB of the *ASME Boiler and Pressure Vessel Code,* Section 3, shall be met.

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Periodic Inspection of CANDU Nuclear Power Plant Components

A National Standard of Canada

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CAN/CSA-N285.4-94
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CSA Standard CAN/CSA-N285.4-94, *Periodic Inspection of CANDU Nuclear Power Plant Components,* consists of **61 pages** (xiv preliminary and 47 text), each dated **December 1994.**

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Preface

This is the third edition of CSA Standard N285.4 (now CAN/CSA-N285.4), *Periodic Inspection of CANDU Nuclear Power Plant Components.* It supersedes the previous editions published in January 1983 and January 1978. This Standard is one of a series of CSA Standards forming a code for CANDU nuclear power plant components.

This Standard is intended to provide uniform rules for the periodic inspection of CANDU nuclear power plant components. It should be understood that this document does not have force of law until adopted officially by the regulatory authority, also that the authority, even though having adopted it, should be consulted as to the extent of such adoption, as the Standard may have been adopted with exemptions or additional requirements.

Users of this Standard are reminded that the design, manufacture, construction, commissioning, operation, and decommissioning of nuclear facilities in Canada are subject to the provisions of the *Atomic Energy Control Act* and Regulations. Thus, requirements additional to those specified in this Standard may be imposed by the Atomic Energy Control Board.

This Standard was prepared by the CSA Technical Committee on Periodic Inspection of CANDU Nuclear Power Plants under the jurisdiction of the Standards Steering Committee on Nuclear Standards and was formally approved by these Committees. It has been approved as a National Standard of Canada by the Standards Council of Canada.

December 1994

Notes:

(1) *Use of the singular in this Standard does not exclude the plural (and vice versa) when the sense allows.*

(2) *Although the intended primary application of this Standard is stated in its Scope, it is important to note that it remains the responsibility of the users of the Standard to judge its suitability for their particular purpose.*

(3) *This publication was developed by consensus, which is defined by* CSA Regulations Governing Standardization *as "substantial agreement reached by concerned interests. Consensus includes an attempt to remove all objections and implies much more than the concept of a simple majority, but not necessarily unanimity." It is consistent with this definition that a member may be included in the Technical Committee list and yet not be in full agreement with all clauses of the publication.*

(4) *CSA Standards are subject to periodic review, and suggestions for their improvement will be referred to the appropriate committee.*

(5) *All enquiries regarding this Standard, including requests for interpretation, should be addressed to Canadian Standards Association, Standards Development, 178 Rexdale Boulevard, Rexdale, Ontario M9W 1R3. Requests for interpretation should*

(a) define the problem, making reference to the specific clause, and, where appropriate, include an illustrative sketch;

(b) provide an explanation of circumstances surrounding the actual field condition; and

(c) be phrased where possible to permit a specific "yes" or "no" answer.

Interpretations are published in CSA's periodical Info Update. *For subscription details, write to CSA Sales Promotion,* Info Update, *at the address given above.*

Inspection Rationale

When preparing a Canadian nuclear code relating specifically to CANDU nuclear power plants, it was considered essential to include a Standard on the periodic inspection of nuclear pressure-retaining components and their supports.

It has long been the practice to carry out extensive in-service inspections of power plant components to provide assurance against plant outages and economic loss from component failures. In addition, in-service inspections are performed in the interest of safety of plant personnel. In the case of nuclear plants, periodic functional testing of safety systems and their components is already performed at appropriate intervals to provide assurance that they have adequate availability. Periodic inspection represents yet another form of in-service inspection.

The purpose of periodic inspection is to provide an assurance that the likelihood of a failure that could endanger health and safety has not increased significantly since the plant was put into service. It is necessary, therefore, to establish first by what means health and safety might be endangered.

On nuclear sites, the major concern is the accidental release of radioactive products. Generally, Canadian safety requirements demand that there should be at least two barriers or containing boundaries between the hazardous sources and the environment at large. In this Standard, emphasis is placed on those systems, or portions of them, that form part of such a barrier or containing boundary.

Unfortunately, systems whose failure can cause the severest hazards are usually the ones with the highest residual radiation fields with the reactor shutdown. Inspection of these systems, therefore, involves some exposure to radiation fields and thus creates a hazard of the same general type as that which it is intended to prevent. Consequently, the approach has been to develop an inspection program that will provide sufficient evidence to adequately assess the integrity of the plant and minimize the overall hazard.

In determining the basis for periodic inspection it is useful to consider "quality status" of the components in question at the time the plant is placed in operation. It is assumed that the components are in a satisfactory condition at the start of the plant operation, and that, if operated in accordance with the design intent, the components will last for their intended service life without failure of the fluid-retaining boundary.

If this is not so, then additional manufacturing inspections should be instituted. Periodic inspection is not intended to discover flaws or weaknesses overlooked during the stages prior to plant start-up, nor should it be implemented as a means of providing additional manufacturing or installation inspection. In addition, during the design stage, emphasis must continue to be put on eliminating the possibility of systems failing. Periodic inspection is not a substitute for eliminating potential failures at the design stage.

Briefly, design and manufacturing inspections are intended to provide an adequately defect-free product at start-up; periodic inspection is intended to ensure that an unacceptable degradation in component quality is not occurring and that the probability of failure remains acceptably low for the life of the plant.

The scope of periodic inspection is considered to include the fluid boundary portions of components and piping and supports that comprise

(a) systems containing fluid that directly transports heat from nuclear fuel;

(b) systems essential for the safe shutdown of the reactor or the safe cooling of the fuel, or both, in the event of a process system failure; and

(c) other systems or components whose failure could put in jeopardy the integrity of system (a) or (b), or both.

In determining the extent of the periodic inspection for the foregoing systems, the following guidelines have been applied:

(a) sufficient system components and piping are to be included to ensure that any general deterioration from corrosion, erosion, or wear is identified. This is intended to ensure that the basic substantial margins provided in the original design, in terms of pressure boundary operating stresses, are not reduced significantly;

(b) all components should be included to an appropriate extent where the massive failure of such a component could severely tax the capability of any of the safety systems; and

(c) all components should be included to an appropriate extent where the failure could lead to or involve substantial impairment of a safety system, preventing its proper operation, or lead to major damage of a process system with consequences as in Item (b).

One other aspect may be considered in determining the scope of periodic inspection. It is common engineering practice to carry out pre-service and in-service inspections on sample components when such components or materials are used beyond conditions of proven experience.

Where such components or materials constitute a part of a vital system, they may be considered suitable candidates for inclusion in the periodic program even though they may fall outside the scope of periodic inspection as defined by the Standard. They would then be included in the program until sufficient experience has been gained to determine that periodic inspection is no longer warranted or that appropriate periodic inspection requirements can be specified. The fuel channel pressure tubes used in the CANDU reactor are considered by the regulatory authorities to fall in this category, and dimensional and volumetric inspections, and material surveillance have been included in the periodic inspection requirements. Similarly, volumetric inspections for steam generator tubes, and thickness checks and visual inspections for the fuel channel feeder pipes have been included.

For other fluid boundary failures, where the probability of occurrence represents only a very small part of the permitted unsafe process failure frequency or where the resulting hazard is relatively slight, or both, periodic inspection is not required. This is because the cost of such additional inspection is not warranted, but also the principle of minimizing the overall hazard would not be followed by exposing inspection personnel to radiation in such cases.

If the plant at start-up has adequately defect-free components, periodic inspection can logically be based on a sampling approach, provided, of course, that the samples are chosen to include areas subject to the most extreme conditions. To ensure this, samples are chosen to include at least the following:

(a) the most significant acceptable indications discovered during the inaugural inspection;

(b) areas most subject to corrosion or erosion; and

(c) areas having the severest conditions of service in terms of stresses, particularly cyclic.

Clearly, the sample areas combining two or more of these factors are particularly appropriate.

These sample areas would logically be used for successive periodic inspections because, in the absence of new evidence, the basis on which they were initially chosen would remain appropriate. Of course, should new evidence arise, the inspection areas should be altered accordingly.

In choosing the inspection sample, effects beyond normal operation such as earthquakes or LOCAs (Loss of Coolant Accidents) are excluded from the stress criteria. As a result, inspection is concentrated on those areas undergoing the most severe operational conditions, since it is these that could potentially suffer the greatest deterioration. Extra inspections beyond the

scope of this Standard may be required after abnormal events.

The number of samples and the extent of each can only be determined logically with reference to a particular design. Logical criteria include those factors defined above relating to the choice of samples, and consideration of the number of like components in a system ("like" in the sense of initial design, manufacture, and subsequent service environment).

An extension of the latter consideration applies to a multi-unit power plant. The sampling required is not the same for all units. The first unit of a power plant in service serves as a basis for all units, with enough samples in each of the other units to identify positively the effects of different service conditions, manufacturing differences, etc, between the units.

In agreement with this basic line of reasoning, the interval between periodic inspections should be determined on a logical basis and not by a fixed time cycle. Consequently, the initial period to the first inspection should be relatively short, to ensure conservatism. Subsequent periods are determined by the severity of operating conditions, evidence from earlier inspections, and considerations of any known abnormality in operation. If this practice is followed, then it can be assumed that the samples represent, with a high degree of certainty, the worst cases, and hence the adequacy of the remainder of each system can be assumed to be no worse.

It will be realized, then, that periodic inspection is a practice for detecting deterioration, a negative characteristic. It involves comparison and hence it is beneficial to have a base line from which to start. An inspection known as inaugural inspection is therefore made, before start-up of the plant, of all areas intended to receive subsequent periodic inspection. However, inaugural inspection is not considered to be necessary for items that, for economic reasons, are normally replaced rather than repaired, provided that spares of such items are readily available.

The methods and techniques for nondestructive examination are still evolving. There is continuing research and development for new methods and better techniques. Therefore, the requirements have been compiled with a certain degree of permitted flexibility to allow the use of new techniques and practices that may be developed, so that a better assurance of the actual level of integrity or a reduction in hazards to the inspection staff, or both, can be obtained.

A strong attempt has been made to set the inspection program on a firm and rational basis by considering not only the consequences of failure but also the factors that determine the likelihood of such failures. Also, the requirements established offer some incentive to the designers and plant operators to limit the extent of the periodic inspection required by providing systems having greater demonstrated quality and integrity.

CAN/CSA-N285.4-94
Periodic Inspection of CANDU Nuclear Power Plant Components

1. Scope

1.1
This Standard defines the requirements for periodic inspection of pressure-retaining components and their supports that form part of a CANDU nuclear power plant.

1.2
This Standard deals with failure aspects, classification of areas subject to inspection, responsibilities, provision for access, inspection techniques and procedures, personnel qualifications, frequency of inspection, documentation, records, evaluation of inspection results, disposition, and repair requirements.

1.3
The values given in SI (metric) units are to be considered the standard. The values given in parentheses are for information only.

2. Reference Publications and Definitions

2.1 Reference Publications
This Standard refers to the following publications and where such reference is made it shall be to the edition listed below. Later issues of these documents can be used if approved by the regulatory authorities:

CSA Standards
CAN/CSA-N285.0-M91,
General Requirements for Pressure-Retaining Systems and Components in CANDU Nuclear Power Plants;

CAN/CSA-N285.2-M89,
Requirements for Class 1C, 2C, and 3C Pressure-Retaining Components and Supports in CANDU Nuclear Power Plants;

CAN/CSA-N285.6 Series-88,
Material Standards for Reactor Components for CANDU Nuclear Power Plants.

ASME* Boiler and Pressure Vessel Code
Section III,
Nuclear Power Plant Components-1992;

Section V,
Nondestructive Examination-1992 including 1993 Addenda;

Section IX,
Welding and Brazing Requirements-1992;

Section XI,
In-Service Inspection-1992 including 1993 Addenda.

CGSB† Standards
48-GP-4M-1978,
Certification of Nondestructive Testing Personnel (Industrial Radiography Method);

48-GP-7M-1979,
Certification of Nondestructive Testing Personnel (Industrial Ultrasonic Method);

48-GP-8M-1979,
Certification of Nondestructive Testing Personnel (Magnetic Particle Method);

48-GP-9M-1979,
Certification of Nondestructive Testing Personnel (Liquid Penetrant Method);

48-GP-13M-1979,
Certification of Nondestructive Testing Personnel (Eddy Current Method).

Acts and Regulations
Atomic Energy Control Act and Regulations of the Federal Government of Canada.

Appropriate Acts and Regulations of each Province of Canada covering Boilers and Pressure Vessels.

**American Society of Mechanical Engineers.*
†Canadian General Standards Board.

2.2 Definitions

The following definitions apply in this Standard:

Act — the act, regulation, or ordinance covering boilers and pressure vessels of the respective province. When reference is made to the *Atomic Energy Control Act* of the federal government, the full title will be used.

Authorised inspection agency — an organisation designated by the Department (see definition of Department) as authorised to perform inspections.

Authorised inspector — a person
(a) appointed under the provisions of the Act and employed by the Department; or
(b) employed by an Authorised Inspection Agency acceptable to the Department.

Component — a registered item including integral supports (eg, vessel, pump, valve, overpressure protection device, fitting, instrument) for a pressure-retaining system (concrete items of the containment system excepted).

Containment boundary — structures and components that enclose nuclear process systems to provide a pressure-retaining barrier.

Containment system — structures and components of the containment boundary and the systems for the handling of fluids (gases, vapours, and liquids).

Defect — an unacceptable indication.

Department — (as used in this Standard) means the department or the ministry of a provincial government charged with enforcement of the Act.

Dissimilar metals — metals that are classified in Section IX of the ASME *Boiler and Pressure Vessel Code* under different "P numbers".

Fast neutron fluence — the product of equivalent full power hours and peak neutron flux (for neutrons greater than or equal to 1.0 MeV).

First net power — the event when electrical energy generated by the reactor unit exceeds the service load of the unit for the first time.

Inaugural inspection — a mandatory inspection carried out on a plant, system, or component prior to start-up, to provide data on initial conditions.

Indication — the evidence or signal revealed by nondestructive examination.

Inspection area — the weld and the base metal up to one-half the weld thickness, and in no case shall it be less than 13 mm (1/2 in) as measured from the edge of the final weld preparation, including any repair preparation, or from the edge of a fillet weld having no weld preparation.

Level A, B, C, and D conditions — service conditions as specified in the relevant design documents for which Level A, B, C, and D service limits are designated, as defined in Section III of the ASME *Boiler and Pressure Vessel Code.*

Licence — a legal permit issued by the regulatory authority.

Mechanical coupling — an item or set of items used to secure the assembly of two or more parts, and which permits subsequent intentional disassembly conditions where corrosion effects are
(a) known to be negligible; or
(b) reduced by chemistry or temperature control so that the reduction in material thickness over the intended service life does not exceed the smaller of 1.5 mm (0.06 in) or 6% of the wall thickness.

Non-erosive conditions — conditions where the erosive effects over the intended service life do not reduce the material thickness by the smaller of 1.5 mm (0.06 in) or 6% of the wall thickness.

Nuclear power plant — a plant producing thermal energy from nuclear fuel, consisting of one or more reactor units.

Owner — the company or organization that is the holder of a licence issued pursuant to the *Atomic Energy Control Act* for the operation of a nuclear power plant.

Periodic Inspection —
(a) mandatory inspection of components carried out at intervals following the start-up of a plant, in accordance with the requirements of this Standard; and
(b) the total program comprising both the inaugural inspection and the periodic inspection defined in Item (a).

Permanent records — information that is retrievable and stored for the life of the plant. Such information may be in the form of written documents, radiographs, "write once" optical discs, or other means that are recognized by Archives Canada for long term storage.

Pipe run — a length of piping that extends to, but not beyond, a large component (eg, vessel, pump) or a piping intersection. The pipe run may extend beyond an intersection where the run pipe has an extruded outlet or a weld-on fitting for the branch connection.

Process system — a system associated with the normal operation of a nuclear power plant.

Radiation — the emission of alpha and beta particles, gamma radiation, and neutrons.

Radioactive substances — substances containing isotopes that are characterized by spontaneous emission of radiation.

Reactor unit — the nuclear power plant pertaining to a single nuclear reactor.

Regulatory authority — any government agency having jurisdiction under the *Atomic Energy Control Act* and the Regulations thereto over the design and operation of pressure retaining systems in CANDU nuclear power plants.

Safety report — a prescribed report prepared by or on behalf of the owner in support of an application for a licence.

Serious process failure — as defined in the Atomic Energy Control Board (AECB) Reactor Licensing and Safety Requirements.

Spared replacement — an item that has all of the following characteristics:
(a) the item would normally be replaced rather than repaired;
(b) a replacement for the item is available; and
(c) the process of replacement does not involve welding or brazing.

Supplementary inspection — an inspection performed to provide assurance of integrity for a component that is being used beyond conditions of proven experience.

Vessel — a component registered with the provincial authority as a boiler or pressure vessel.

Weld intersection — the intersection of two or more welded joints, including T, Y, and X configurations.

Weld zone — the weld and the base metal up to 13 mm (1/2 in) from the edge of the final weld preparation, including any repair preparation, or from the edge of fillet welds having no weld preparation.

3. General Requirements

3.1 Postulates

3.1.1 Nature of Inspection

The periodic inspection shall be conducted in a realistic and logical manner to provide, within the capabilities of current techniques, an assurance of the improbability of a failure that may produce conditions exceeding the health and safety limits for normal operation as stated in the safety report.

3.1.2 Prerequisites

3.1.2.1

The systems are to be operated in accordance with their design intent.

3.1.2.2
All specified inspections, examinations, tests, etc, that ensure the components are acceptable for service have been performed.

3.1.3 Power Plant Operation

3.1.3.1
Periodic inspection is primarily intended to ascertain any change in the integrity of systems due to operation under conditions classified as Level A or B.

3.1.3.2
Additional inspections shall be considered if conditions exceeding Level A and B are experienced.

3.2 Hazards

3.2.1
Inspection requirements of this Standard pertain to the prevention of the release of radioactive substances.

3.2.2
At CANDU power plants generally, the absence of significant quantities of toxic or flammable products, or both, and the size of the exclusion zone virtually eliminate any hazard from other than radioactive sources. However, if such hazards do exist, then appropriate inspections shall be performed.

3.3 Inspection Regions

3.3.1 Systems Subject to Inspection
The systems subject to inspection shall include the following or portions thereof:
(a) systems, and systems connected thereto, containing the fluid that, under normal conditions, directly transports heat from nuclear fuel, and other systems whose failure may result in a significant release of radioactive substances;
(b) systems essential for the safe shutdown of the reactor and/or the safe cooling of the nuclear fuel in the event of a process system failure; and
(c) systems the failure or dislodgment of which could jeopardize the integrity of systems in Item (a) or (b), or both. Included are large pieces of rotating machinery (eg, flywheels).

3.3.2 Extent of System Subject to Inspection

3.3.2.1
The inspection requirements shall apply to the fluid boundary portions of all components and piping and to their supports, unless stated otherwise in this Standard. Areas of supports where the largest principal stresses are compressive need not be inspected.

3.3.2.2
The fluid boundary as specified in Clause 3.3.2.1 shall be in accordance with the following:
(a) For systems containing nuclear fuel or for systems connected to such systems, the fluid boundary subject to inspection shall extend to and include any portion that does not have
(i) two additional barriers between the fluid boundary and the sheathing of the nuclear fuel; or

(ii) two additional barriers between the fluid boundary and the outside atmosphere; or

(iii) one barrier between the fluid boundary and the sheathing of the nuclear fuel and one barrier between the fluid boundary and the outside atmosphere.

(b) The number of barriers in Item (a) shall be determined as follows:

(i) metal boundary (eg, vessel wall) — equal to one barrier;

(ii) valves: manual, automatic, or remotely controlled — that are normally closed during Level A operating conditions — equal to one barrier;

(iii) valves: self-closing that may be open during Level A operating conditions — equal to 1/2 barrier;

(iv) valves: manual — that may be open during Level A operating conditions shall not be considered, unless it can be shown that closure could reasonably be expected within a time period consistent with permissible radiation releases — equal to 1/2 barrier;

(v) containment boundary — equal to one barrier.

(c) For other systems, whose failure may result in a significant release of radioactive substances, the fluid boundary subject to inspection shall extend to and include any portion whose failure may permit such release.

(d) Where it can be demonstrated to the satisfaction of the regulatory authority that in the event of failure of a system or portion thereof, covered by Item (a) or (c), without operation of the containment system, any resulting hazard to the public would be less than the AECB dose limits for a serious process failure, then such system or portion shall be exempted from periodic inspection.

3.3.2.3

For systems essential for the safe shutdown of the reactor or the safe cooling of the nuclear fuel, or both, in the event of a process system failure,

(a) the fluid boundary subject to inspection shall extend to and include any portion whose failure would prevent adequate functioning of the system, except as modified by Item (b);

(b) any portion of a system that is normally in a dormant or standby condition may be exempt from inspection, provided that either

(i) it is monitored, and pressurised at all times with the reactor under Level A conditions to a pressure equal to or greater than that occurring during system operation; or

(ii) it is subjected to a periodic testing program acceptable to the regulatory authority, that assures pressure retaining integrity.

3.3.2.4

For systems whose failure could jeopardize the integrity of any system included in Clauses 3.3.2.2 and 3.3.2.3,

(a) the fluid boundary of vessels subject to inspection shall extend to and include all nozzle-to-vessel attachment welds;

(b) component supports (eg, for piping, vessels, pumps, and valves) and rotating machinery whose structural integrity is relied upon to withstand the design loads and seismically induced displacements shall be subject to inspection;

(c) components in systems that are completely filled with liquid at temperatures below that corresponding to a vapour pressure of 350 kPa (50 psi) and whose supports are shown to be adequate to withstand the forces resulting from failure of the fluid boundary shall be exempt from this inspection.

3.4 Radiation Exposure

3.4.1
The intent of periodic inspection is to provide assurance that the integrity of components whose failure could result in significant radiation exposure is maintained.

3.4.2
A periodic inspection normally incurs exposure of the inspection personnel to radiation. Consideration shall be given to ensure that exposures are kept to a minimum consistent with providing an adequate indication of system integrity.

3.4.3
Where the dose rate is such that the radiation exposure resulting from inspection would be excessive, the inspection program may be reviewed and a modified program submitted to the regulatory authority for approval.

3.5 Program Document

3.5.1
Programs specific to a reactor unit shall be prepared. The documents may be compiled and issued in discrete parts.

3.5.2
The programs shall contain the information necessary to substantiate
(a) selection of systems and components subject to inspection (see Clause 3.3);
(b) categorization/screening of components for inspection (see Clause 7.1);
(c) selection of inspection methods and procedures (see Clauses 4, 7.2, 12, 13, and 14);
(d) selection, location, and extent of inspection areas (see Clauses 7.4, 12, 13, and 14);
(e) inspection for identical components and for subsequent units in multi-unit power plants (see Clauses 7.5, 12, 13, and 14);
(f) inspection interval (see Clauses 7.6, 12, 13, and 14); and
(g) code effective dates for design registration.

3.6 Owner's Responsibility
The owner of the nuclear plant shall be responsible for the inspections required by this Standard. The responsibility shall include
(a) preparation and updating of the program document as required by Clause 3.5.2 and its submission to the regulatory authority for approval;
(b) preparation of written inspection instructions and procedures (including diagrams and drawings) delineating the identification and extent of inspection areas;
(c) scheduling the inspections;
(d) verification of the qualifications and proficiency of inspection personnel;
(e) performance demonstrations of the adequacy of the procedures and the proficiency of the personnel using the assigned equipment to detect and size flaws in representative samples;
(f) arrangement for accessibility;
(g) performing the inaugural and periodic inspections required;
(h) evaluation of results;
(i) reporting of results;
(j) maintenance and retention of records; and
(k) retention and control of nondestructive examination calibration specimens.

3.7 Accessibility

3.7.1 Access for Inspection

The design and arrangement of components and piping shall provide for clearances adequate to permit all inspections required by this Standard.

3.7.2 Access for Appointed Inspector

The owner shall arrange for the inspector (see Clause 3.8) to have access to the parts of the plant necessary for the required inspections. The owner shall keep the inspector informed of the progress of the preparatory work and shall provide notification reasonably in advance of when the components will be ready for inspection.

3.8 Appointed Inspector

The regulatory authority shall appoint an inspector under the provisions of the *Atomic Energy Control Act,* or shall arrange for an authorised inspector appointed by the department of the province of installation to act on behalf of the regulatory authority regarding conformance with laws of general application with the province.

The inspector shall, to the extent deemed necessary,

(a) verify that the designated inspection methods are used;

(b) verify that the inspections are performed in accordance with procedures, by personnel qualified in accordance with this Standard;

(c) require requalification of any procedure or inspection personnel when the inspector has a specific reason to question the ability of the procedure or the personnel to meet the specified requirements; and

(d) review the inspection records to ensure that the requirements have been met.

4. Inspection Methods and Procedures

4.1 Methods

4.1.1

Inspection methods employed should be limited to those which can be classified as nondestructive.

4.1.2

Any method or technique employed shall be capable of yielding results to an acceptable standard in one or more of the following groups. A method capable of yielding results to an acceptable standard in several groups shall be given preference over other methods that are acceptable in fewer groups.

(a) **Visual.** This includes, but is not restricted to, inspection for determining corrosion, erosion, distortion, position, alignment, wear, leakage, defects, fractures, completeness, and deterioration by methods such as direct visual and visual aids (eg, telescope, borescope, closed circuit television);

(b) **Dimensional.** This includes, but is not restricted to, inspection for determining size, configuration, distortion, wear, alignment, corrosion, and erosion by such methods as direct measurement (eg, scale, micrometer, vernier callipers, gauges) and indirect measurement (eg, theodolite, ultrasonic and electronic methods);

(c) **Surface and Volumetric.** This includes, but is not restricted to, inspection for determining discontinuities (ie, surface, subsurface, or internal) by methods such as liquid penetrant, magnetic particle, ultrasonic, radiographic, and eddy current.
(d) **Integrative.** This includes, but is not restricted to, monitoring overall component integrity such as leak detection, acoustic emission, and strain measurement.

4.1.3
Inspections required by this Standard shall be performed using the methods and techniques that are listed in Table 1.

4.1.4
Approval from the regulatory authority shall be obtained for the use of radiographic methods.

4.2 Procedures

4.2.1
A procedure shall be written for each inspection method to be employed.

4.2.2
Unless otherwise specified in this Standard, the procedure shall meet or exceed the requirements of the ASME *Boiler and Pressure Vessel Code,* Section V.

4.2.3
The acceptance and recording criteria of Clauses 8, 12, 13, and 14 shall apply.

4.2.4
The requirements of this standard take precedence over any conflicting conditions specified in the ASME *Boiler and Pressure Vessel Code,* Section V.

4.2.5
The requirements for ultrasonic examination in accordance with ASME Section V, Article 4 are modified as follows:
(a) **Applications** — the requirements of Article 4, except the limitation of material thickness, shall apply to all weld examinations.
(b) **Scan angles** — weld examinations are to be conducted with two angle beams separated by at least 10°.
(c) **Probe overlap** — when a manual scan technique is used, the required examination volume shall be scanned with a minimum overlap of 10% of the transducer dimension perpendicular to the direction of the scan if ±30° probe oscillation is achieved. Automatic scanners shall provide demonstrated beam overlap of at least 50% transducer dimension overlap.
(d) **Sizing of indications in weld zone** — length dimension is determined using the 6 dB drop method. This utilizes the probe travel distance at the positions where the echo amplitude is reduced by 6 dB with respect to the maximum echo amplitude. The through wall dimension is determined using the 6 dB/half beam width method. This dimension is proportional to the differences in beam path distances at positions where echo amplitude is reduced by 6 dB from the maximum amplitude and the probe travel distances are corrected by the 6 dB beam profile. Refer to Article 4 non-mandatory Appendix B-60, *Beam Spread, Vertical Plane.*

4.2.6
A procedure that deviates from the above requirements shall be submitted to the regulatory authority and approval obtained before inspection commences.

4.2.7
A procedure for a method not included in the ASME *Boiler and Pressure Vessel Code,* Section V, shall employ the current practice for that method. The procedure shall be submitted to the regulatory authority and approval obtained before inspection commences.

5. Inspection Personnel

5.1 Personnel Qualifications

5.1.1
Inspection personnel shall be
(a) certified in accordance with the appropriate CGSB 48-GP Standard(s) for the nondestructive examination method(s) to be employed;
(b) certified in accordance with the requirements of other appropriate standards for the methods in (a) above and be accepted by the regulatory authority; or
(c) verified by the owner to be qualified and be accepted by the regulatory authority for other methods.

5.1.2
Inspection personnel shall be verified by the owner as qualified for the inspection method to be employed, and accepted by the regulatory authority as adequate to perform designated inspections.

6. Inaugural Inspection

6.1 Inspection Program

6.1.1 Time of Inspection

6.1.1.1
Inaugural inspection for other than thickness measurement shall be performed either
(a) during or after the component hydrostatic pressure test but before start-up of the reactor; or
(b) before the component hydrostatic test, provided that a confirmatory inspection, as required by Clause 6.1.4, is performed after the component hydrostatic pressure test and the results indicate no significant change.

6.1.1.2
Inaugural inspection for thickness measurement may be performed at any time before reactor start-up.

6.1.1.3
Where the fluid boundary of a component or system that is subject to periodic inspection is repaired or replaced, it shall receive an inaugural inspection before being put into service.

6.1.1.4

Where the periodic inspection program is amended, eg, the system pressure boundary is reduced, extended, etc, or new inspection areas are added due to new conditions, inaugural inspection shall be performed as required by this Standard before putting the component(s) or system(s) into service.

6.1.2 Extent of Inspection

Inaugural inspection shall be performed on all components, supports, and portions of systems required by this Standard to receive periodic inspection, and on all replicas of such components, supports, and portions of systems.

6.1.3 Inspection Areas

6.1.3.1

General requirements are as follows:

(a) the full thickness of the inspection area shall be covered when volumetric methods are used. Each inspection area shall be sufficient to permit inspection of a reasonable amount of base metal and, if the inspection area includes a welded joint, the full width of the weld zone;

(b) the inspection area of each side of a welded joint shall extend for a minimum distance of one-half the material thickness from the point of maximum width of the final weld preparation, and in no case shall it be less than 13 mm (1/2 in). For butt welds the material thickness shall be considered to be equal to the mean weld thickness. For fillet welds having no weld preparation the inspection area shall be measured from the edge of the weld; and

(c) the inspection area shall extend for the full length of the welded joint.

6.1.3.2

Inspection areas for each type of equipment are defined in the following items:

(a) **Piping.**

(i) full thickness of all category A or B welded joints (see Clause 7.4); and

(ii) full thickness of all dissimilar metal welded joints where failure would be defined by Clause 7.1.2 as large or medium failure.

(b) **Vessels.** Full thickness of all category A or B pressure-retaining welded joints (see Clause 7.4), except that nozzles, openings, and penetrations may be excluded when their internal diameter is not greater than $0.2\sqrt{tR}$.

where

R = mean radius of shell or head

t = nominal thickness of shell or head

(c) **Mechanical Couplings.**

(i) Bolting — the manufacturing inspection shall be considered as satisfying the inaugural inspection requirements for the complete fastener (eg, bolt, stud, nut). Manufacturing inspection data need not be kept in the inaugural inspection records;

(ii) Flange ligaments — the flange ligaments between threaded stud holes, for studs defined as category A or B; and

(iii) Other components — the inspection areas shall be based on periodic inspection requirements.

(d) **Pumps.** Full thickness of all category A or B (see Clause 7.4) pressure-retaining welded joints.

(e) **Valves.** Full thickness of all category A or B (see Clause 7.4) pressure-retaining welded joints.
(f) **Supports.**
(i) the entire support, for supports defined as category A or B. Inspection shall include the support settings of constant and variable spring-type hangers, snubbers, and shock absorbers; and
(ii) all attachment welds that are category A or B.
(g) **Rotating Machinery** — all regions defined as category A or B.

6.1.3.3
Thickness measurements shall be performed on all areas that are selected for periodic inspection in accordance with Clause 7.4.7.

6.1.4 Confirmatory Inspection

6.1.4.1
Confirmatory inspection, when required by Clause 6.1.1, shall employ the method used for the inaugural inspection.

6.1.4.2
Areas to be inspected shall include the following:
(a) **Piping.** The most significant indications detected previously such that the number of inspection areas equals at least 10% of the periodic inspection sample for the system.
(b) **Vessels.**
(i) the full length of all major nozzle welds; and
(ii) the most significant indications detected previously in the longitudinal and circumferential joints such that at least 10 periodic inspection areas (or all if fewer than 10 exist) per component or 10% of the indications, whichever is greater, are inspected.
(c) **Pumps.** At least 10% of the pumps shall be inspected. Pump inspection shall include all category A and B pressure-retaining welded joints.
(d) **Valves.** At least 10% of the valves shall be inspected. Valve inspection shall include all category A and B pressure-retaining welded joints.

6.2 Inspection Methods and Procedures

6.2.1 Methods
The method or technique planned to be employed for the subsequent periodic inspections shall be used.

6.2.2 Procedures
The procedures for each inspection method or technique employed shall comply with the requirements of Clause 4.2.

6.3 Inspection Personnel
The requirements given in Clause 5 shall apply.

6.4 Evaluation of Results

6.4.1
Results of each inspection shall be evaluated according to Clause 8.

6.4.2
When an indication is found during inaugural inspection that exceeds the manufacturing acceptance standards, it may be left as is, provided
(a) the owner can demonstrate to the regulatory authority that the defect will not impair safe operation of the system; and
(b) a monitoring program is established for periodic evaluation.

6.5 Records

6.5.1
Records of inaugural inspections shall be kept for comparison with the results of subsequent periodic inspections.

6.5.2
The inaugural inspection records shall comply with the requirements of Clause 11.

7. Periodic Inspection

7.1 Inspection Categories

7.1.1 Considerations
The inspection areas and the degree of inspection required shall be determined by considering the safety margin and the magnitude and type of failure as defined in Clauses 7.1.2 to 7.1.4. The method for determining the inspection category is defined by Clause 7.1.5.

7.1.2 Size of Failure

7.1.2.1
For components in systems classified under Clause 3.3.1(a) located inside the containment boundary, considering Level A and B conditions, the following procedure shall be used:
(a) **Piping, Pumps, and Valves**
(i) the size of failure shall be expressed as the ratio of the maximum energy release rate from the failure being considered to the maximum energy release rate from the most severe failure considered during the design of the systems that directly transport heat from the nuclear fuel;
(ii) where the maximum energy release ratio (R_E) is not determined by detailed analysis, it shall be determined as follows:

$$R_E = \frac{A_F}{A_D} \times \frac{h_F}{h_D} \times \frac{\sqrt{P_F}}{\sqrt{P_D}} \times \frac{\sqrt{\rho_F}}{\sqrt{\rho_D}}$$

where

A = flow cross-sectional area (guillotine failure)

h = enthalpy at operating temperature and pressure minus the enthalpy of saturated liquid at atmospheric pressure

P = operating pressure (gauge)

ρ = density of fluid

subscript $_F$ = conditions for location being considered

subscript $_D$ = conditions for design maximum energy release rate; and

(iii) failure size classification shall be as follows:

(1) **Small failures** — failures where the value of R_E is 0.1 or less;

(2) **Medium failures** — failures where the value of R_E is greater than 0.1 and less than 0.3;

(3) **Large failures** — failures where the value of R_E is 0.3 or greater.

(b) **Vessels**

(i) a size of failure based on energy release rate shall be determined as in Clause 7.1.2.1(a), using flow cross-sectional areas of the lines connected to the vessel that would continue to supply fluid to the failure;

(ii) a failure size based on containment pressure rise shall also be determined. It shall be expressed as the ratio of the immediate containment pressure rise caused by the instantaneous release of fluid in the vessel, assuming a sealed containment, to the lowest pressure rise required to cause closure of the containment ventilation system;

(iii) where the containment pressure rise ratio (R_V) is not determined by detailed analysis, it shall be determined as follows, assuming uniform vapour distribution and no fluid heat loss:

W_L = maximum weight of liquid in vessel (operating conditions)

h = enthalpy of liquid at operating conditions

h_f = enthalpy of saturated liquid at normal containment pressure, P

h_{fg} = enthalpy of evaporation at pressure P

W_g = weight of vapour produced,

$$= \frac{W_L (h - h_f)}{h_{fg}}$$

V_g = specific volume of saturated vapour at pressure P

V_T = vapour volume at pressure P, $V_T = W_g \times V_g$

V_C = containment volume

P_c = containment pressure rise, $P_c = P \times \frac{V_T}{V_c}$

P_s = lowest containment pressure rise to cause closure of containment ventilation system then

$$R_V = \frac{P_c}{P_s}$$

(iv) failure size classification based on containment pressure rise shall be as follows:

(1) **Small failures** — failures where the value of R_V is less than 1;

(2) **Medium failures** — failures where the value of R_V is from 1 to 3;

(3) **Large failures** — failures where the value of R_V is greater than 3; and

(v) if the two failure sizes determined from R_E and R_V differ, the larger shall be taken as the size of failure.

(c) **Lines Connecting to Failures** — flow from a line connected to a failed pipe or component need not be included in computing size of failure if the line incorporates two remotely operated or self-closing valves in series, provided that such valves and their power supplies are

(i) not connected to the same power source; and

(ii) sufficiently remote from one another that both would not be subject to damage or malfunction from the same failure.

7.1.2.2

For components in systems classified under Clause 3.3.1(a) located outside or forming part of the containment boundary, all failures capable of causing a hazard equal to or exceeding the AECB dose limits for a serious process failure shall be classified as large.

7.1.2.3

For components in systems classified under Clause 3.3.1(b)

(a) failures that may prevent functioning of the system as described in the safety report shall be considered as large; and

(b) failures that do not prevent functioning of the system as described in the safety report shall be considered as small.

7.1.2.4

For components in systems classified under Clause 3.3.1(c)

(a) the size of failure shall be classified according to the total effect of the initiating and resulting failures;

(b) for dislodgments that may lead to failure of a system classified by Clause 3.3.1(a) the relevant rules in Clause 7.1.2.1 or 7.1.2.2 shall be used to determine the size of failure; and

(c) for dislodgments that may lead to failure of a system classified by Clause 3.3.1(b) the rules in Clause 7.1.2.3 shall be used to determine the size of failure.

7.1.3 Fatigue Usage Factor

7.1.3.1

Fatigue usage factors used in establishing inspection categories shall be those determined by the rules given in ASME *Boiler and Pressure Vessel Code*, Section III.

7.1.3.2

Fatigue usage factor classifications shall be as follows:

(a) **low-fatigue** — factors of 0.01 or less;

(b) **medium-fatigue** — factors greater than 0.01 and less than 0.1; and

(c) **high-fatigue** — factors of 0.1 or greater.

7.1.3.3

Where the fatigue usage factor is not calculated, a value of 0.05 shall be used.

7.1.4 Stress or Stress Intensity

7.1.4.1

Stresses or stress intensities are used to calculate stress ratios as follows:

(a) for Level A and B conditions the calculated stress or stress intensity shall be compared to the allowable stress or stress intensity, such that

$$\text{Stress ratio} = R_s = \frac{\text{Calculated stress or stress intensity}}{\text{Allowable stress or stress intensity}}$$

(b) the use of more than one method of stress calculation may produce different calculated stresses or stress intensities. The calculated stress intensity to be used in Item (a) shall be taken from the most precise method employed. The following methods are listed in order of precision:

(i) methods of analysis more refined than those given in ASME *Boiler and Pressure Vessel Code,* Section III, eg, finite element analysis;

(ii) methods using the rules given in ASME *Boiler and Pressure Vessel Code,* Section III; and

(iii) methods for determining tentative metal thickness and similar formulae given in ASME *Boiler and Pressure Vessel Code,* Section III;

(c) where the stress analysis considers more than one condition, several values of R_s may be obtained. The maximum value of R_s shall be equal to R_{SM}; and

(d) for materials where the value of S_a corresponding to 10^6 cycles is greater than S_m the ratio R_{SM} may be reduced as follows:

$$R_{SA} = \text{stress ratio adjusted} = R_{SM}\frac{S_m}{S_a}$$

where

S_m is defined in ASME *Boiler and Pressure Vessel Code,* Section III NB-3200

S_a is defined in ASME *Boiler and Pressure Vessel Code,* Section III NB-3222

7.1.4.2 Stress Classifications of Inspection Areas

Classifications shall be as follows:

(a) **low stress intensity** — areas where the lesser of R_{SM} and R_{SA} is 1/3 or less;

(b) **medium stress intensity** — areas where the lesser of R_{SM} and R_{SA} is greater than 1/3 and less than 2/3; and

(c) **high stress intensity** — areas where the lesser of R_{SM} and R_{SA} is 2/3 or greater.

7.1.5 Determination of Inspection Category

7.1.5.1

Inspection categories shall be determined as follows:

(a) determine the failure size classification as defined by Clause 7.1.2. Refer also to Clause 7.1.5.2 for mechanical couplings and to Clause 7.1.5.3 for supports;

(b) determine the fatigue usage factor as defined by Clause 7.1.3;

(c) determine the stress classification as defined by Clause 7.1.4;

(d) systems, components, and local areas classified by Clause 7.1.2 as small failure size are designated Category C2;

(e) for systems, components, and local areas classified by Clause 7.1.2 as medium failure size, use Figure 1(a) to determine inspection category;

(f) for systems, components, and local areas classified by Clause 7.1.2 as large failure size, use Figure 1(b) to determine inspection category; and

(g) locate the intersection of the stress intensity and fatigue usage factor on Figure 1(a) or (b), as appropriate, to determine the inspection category (A, B, C1, or C2).

7.1.5.2
For mechanical couplings, the inspection category shall be determined from Figure 1(a) or (b) for the size of failure resulting from complete failure of the connection. The inspection categories for the various items in a coupling may be different.

7.1.5.3
The inspection category for supports shall be determined as follows:
(a) **Piping Supports.** All supports and piping attachment welds for a piping system shall be placed in category A where any portion of the system has a large failure size, and in category B where the maximum failure size in the system is medium.
(b) **Supports for Other Components.**
(i) The entire support shall be placed in category A where the supported component has a large failure size, and in category B where the supported component has a medium failure size.
(ii) For component attachment welds, the inspection category shall be determined from Figure 1(a) or (b) for the size of failure of the supported component. Where a support has two or more component attachment welds, the inspection category for the various welds may be different.

7.2 Inspection Methods and Procedures

7.2.1 Methods
Inspections shall be made using methods and techniques defined in Clause 4.1.

7.2.2 Procedures
The procedure for each inspection method or technique employed shall comply with the requirements of Clause 4.2.

7.3 Inspection Personnel
The requirements given in Clause 5 shall apply.

7.4 Inspection Program

7.4.1 Extent of Inspection

7.4.1.1
The extent of the inspection required shall be determined by the inspection category as defined by Clause 7.1.5 and by the requirements specified in Clauses 7.4.2 to 7.4.7 and in Clause 7.5.

7.4.1.2
For a system or component where operating conditions or operating behaviour differ significantly from that contemplated in the design, the periodic inspection shall be extended to include the system or component and the inspection program shall be determined on a special case basis.

7.4.1.3
No requirement in this Standard shall be interpreted as preventing, if it is deemed desirable, the performance of periodic inspection on an area which had not received an inaugural inspection or for which inspection records are not available.

7.4.1.4

Significant indications found in any component subject to periodic inspection but not selected as or within an inspection area shall be evaluated in accordance with Clause 8 and reported in accordance with Clause 11.

7.4.2 Areas Selected for Inspection

7.4.2.1

General requirements are as follows:

(a) each inspection area shall be sufficient to permit inspection of a reasonable amount of base metal and, if the inspection area includes a welded joint, the full width of the weld zone;

(b) the inspection area on each side of a welded joint shall extend for a minimum distance of one-half the material thickness from the point of maximum width of the final weld preparation, and in no case shall it be less than 13 mm (1/2 in). For butt welds the material thickness shall be considered to be equal to the mean weld thickness. For fillet welds having no weld preparation, the inspection area shall be measured from the edge of the weld;

(c) through-wall coverage of the inspection area, where volumetric methods are required, shall be either:

(i) not less than 1/3 of the nominal wall thickness as measured from the internal surface, providing the external surface is examined using surface examination methods; or

(ii) full wall thickness;

(d) a welded joint that contains weld intersections shall have the inspection area(s) located to cover all such intersections except as modified by Items (e) and (i);

(e) the area that includes the most significant indication in each pipe run or component shall be volumetrically examined; the examination shall be extensive enough to monitor the indication for change. Engineering judgement considering stress state, flaw characterisation and location will be used to determine whether indications are significant;

(f) joints of dissimilar metals shall be considered separately from joints of similar metals;

(g) a welded joint between piping and any other component shall be considered as a piping weld for inspection purposes;

(h) welds provided for sealing purposes only may be excluded from inspection; and

(i) where the stress level is known to vary significantly along the length of a welded joint, the inspection area(s) shall be located to cover the region(s) having the highest stress.

7.4.2.2

The inspection areas for each type of equipment are defined as follows:

(a) **Piping.** The length of the inspection area shall extend for

(i) the full length of a circumferential weld or a branch intersection weld; and

(ii) a minimum of 300 mm (12 in) or three mean weld thicknesses, whichever is the greater, along a longitudinal weld;

(b) **Vessels.**

(i) the length of the inspection area for a pressure-containing weld shall extend along the centre line of the weld for a minimum of 300 mm (12 in), or three mean weld thicknesses, whichever is the greater;

(ii) where the total inspection area for a joint is divided between two or more locations, the length of any inspection area shall be not less than three mean weld thicknesses; and

(iii) nozzles, openings, and penetrations need not be included as an inspection area, when their internal diameter is not greater than

$0.2\sqrt{tR}$

where
R = mean radius of shell or head
t = nominal thickness of shell or head
(c) **Mechanical Couplings.**
(i) **Bolting.** The inspection area shall be considered to include the complete fastener (eg, bolt, stud, nut) and the flange ligaments between threaded stud holes;
(ii) **Other Components.** The inspection area shall be considered on a special case basis;
(d) **Pumps.** The length of the inspection area for a pressure-retaining weld shall extend along the centre line of the weld for a minimum of 300 mm (12 in), or three mean weld thicknesses, whichever is the greater;
(e) **Valves.** The length of the inspection area for a pressure-retaining weld shall extend along the centre line of the weld for a minimum of 300 mm (12 in), or three mean weld thicknesses, whichever is the greater;
(f) **Supports.**
(i) The inspection area of a support shall include the whole support and shall include the support settings of constant and variable spring-type hangers, snubbers, and shock absorbers;
(ii) Component Attachment Welds — the length of the inspection area shall be not less than three material thicknesses of the support material and located, wherever possible, to include the end of the weld;
(g) **Rotating Machinery.** The inspection area shall extend over the entire region falling within the inspection category.

7.4.3 Category A — Inspection Requirements

Material that is in category A shall be inspected as follows:
(a) **Piping.**
(i) One joint in each pipe run shall be inspected. The joint having the highest fatigue usage factor shall be selected for inspection; and
(ii) Where fatigue usage factors are not calculated, the joint having the highest stress ratio shall be selected for inspection;
(b) **Vessels.** All pressure-containing welds shall be inspected, except that the number of identical welds to be inspected may be reduced to F_A as determined by Clause 7.5.1.1(a);
(c) **Mechanical Couplings.**
(i) all bolting shall be inspected;
(ii) all ligaments between threaded stud holes shall be inspected; and
(iii) all other components shall be inspected;
(d) **Pumps.** All pressure-retaining welds shall be inspected;
(e) **Valves.** All pressure-retaining welds shall be inspected;
(f) **Supports.**
(i) all supports shall be inspected;
(ii) all component attachment welds shall be inspected; and
(g) **Rotating Machinery.** All regions shall be inspected.

7.4.4 Category B — Inspection Requirements

7.4.4.1

Material that is in category B shall be inspected as defined in the appropriate item in Clause 7.4.4.4, provided that a leak detection system is in use.

Leak detection means a system that
(a) provides continuous monitoring of leakage; and
(b) has a sensitivity that will readily detect and indicate incremental leakages that are in excess of 0.5 kg/min (1.1 lb/min).

7.4.4.2
When it can be demonstrated to the regulatory authority that a material not complying with the condition in Clause 7.4.4.1 is acceptable, it shall be inspected as defined in the appropriate item in Clause 7.4.4.4.

7.4.4.3
Where the conditions of Clauses 7.4.4.1 and 7.4.4.2 cannot be met, the material shall be placed in category A and inspected according to category A requirements (see Clause 7.4.3).

7.4.4.4
The inspection for material complying with Clause 7.4.4.1 or 7.4.4.2 shall be in accordance with the following:
(a) **Piping.**
(i) For each pipe run having one or more category B regions, the joint having the highest fatigue usage factor shall be inspected, except that if the pipe run has a category A region, no further inspection is required; and
(ii) Where fatigue usage factors are not calculated, the joint having the highest stress ratio shall be selected for inspection.
(b) **Vessels.**
(i) Pressure-retaining welds having the highest fatigue usage factors shall be inspected. The number of welds inspected shall be not less than 1/3 of the category B welds, except that the number of identical welds to be inspected may be reduced to F_B as determined by Clause 7.5.1.1(b); and
(ii) Where fatigue usage factors are not calculated, the joints having the highest stress ratio shall be selected for inspection.
(c) **Mechanical Couplings.**
(i) **Bolting.** 10% of the total number of fasteners in the joint, to the next higher integer, shall be inspected;
(ii) **Flange Ligaments.** 10% of the flange ligaments between threaded stud holes, to the next higher integer, shall be inspected; and
(iii) **Other Components.** The extent of the inspection shall be considered on a special case basis.
(d) **Pumps.**
(i) Pressure-retaining welds having the highest fatigue usage factors in this category shall be inspected. The number of welds inspected shall be not less than 1/3 of the welds in category B; and
(ii) Where fatigue usage factors are not calculated, the welds having the highest stress ratios shall be selected for inspection.
(e) **Valves.**
(i) Pressure-retaining welds having the highest fatigue usage factors in this category shall be inspected. The number of welds inspected shall be not less than 1/3 of the welds in category B; and
(ii) Where fatigue usage factors are not calculated, the welds having the highest stress ratios shall be selected for inspection.

(f) **Supports.**

(i) All supports shall be inspected;

(ii) Where a support has one or more component attachment welds, at least one weld (that having the highest fatigue usage factor) shall be inspected;

(iii) Where fatigue usage factors are not calculated, the component attachment weld having the highest stress shall be selected for inspection.

(g) **Rotating Machinery.** The region that is defined as category B and has the highest stress in this category shall be inspected, except that if the component has a category A region, no further inspection is required.

7.4.5 Category C1 — Inspection Requirements

7.4.5.1

No periodic inspection is required for material that is in this category, provided that it is not composed of dissimilar metals.

7.4.5.2

When it can be demonstrated to the regulatory authority that a material not complying with the condition in Clause 7.4.5.1 is acceptable, no periodic inspection except that called for in Clause 7.4.7 is required.

7.4.5.3

Where the conditions of Clauses 7.4.5.1 and 7.4.5.2 cannot be met, the material shall be placed in category B and inspected according to category B requirements (see Clause 7.4.4).

7.4.6 Category C2 — Inspection Requirements

No periodic inspection is required for material that is in this category.

7.4.7 Additional Requirements — Corrosion and Erosion Inspection Requirements

7.4.7.1

In addition to the foregoing periodic inspection requirements, the following inspections shall be performed to determine the deterioration due to corrosion or erosion, or both.

7.4.7.2 Category A Areas

Inspection requirements are as follows:

(a) where the system or component, except for pumps and valves, is known to operate under conditions that can be classified as noncorrosive and nonerosive, or inspection results on wall thickness are available to prove that non-corrosive and non-erosive conditions exist, no further inspection is required;

(b) for pumps and valves, a dimensional and/or visual inspection of the internal surface of the fluid boundary for loss of material shall be performed. For pumps and valves subject to corrosion-related cracking, surface inspection of the internal fluid boundary shall be performed. The inspection area shall cover not less than 20% of the fluid boundary internal surface and shall include all areas having the greatest potential for corrosion-related cracking to occur;

(c) for components and systems, except pumps and valves, that do not meet the requirements of Clause 7.4.7.2(a), the following dimensional inspections shall be performed:

(i) if non-corrosive conditions do not exist, the material thickness shall be determined at the location in the system considered to have the highest corrosion rate;

(ii) if there is no area in the system that has a corrosion rate significantly greater than the average for the system, the material thickness shall be determined at the location having the highest calculated stress intensity; and

(iii) if non-erosive conditions do not exist, the material thickness shall be determined at the location in the system considered to have the highest erosion rate.

7.4.7.3 Categories B and C1 Areas

The inspection areas in these categories shall be inspected according to the requirements for category A given by Clause 7.4.7.2, except no further inspection is required for systems that have an inspection area included in category A provided that the corrosion and/or erosion, of these areas is not greater than that of the inspected Category A area(s).

7.4.7.4 Category C2 Areas

No additional inspection is required.

7.5 Identical Components

7.5.1 One Reactor Unit

7.5.1.1

Where there are two or more identical components* in one reactor unit, and they are operated under similar conditions, the magnitude of the periodic inspection for such components in one reactor unit shall be determined as follows:

(a) Inspection of category A areas shall be not less than that for a single component multiplied by a factor F_A. The value of F_A shall be determined from the curve F_A in Figure 2.

(b) Inspection of category B areas shall be not less than that for a single component multiplied by a factor F_B. The value of F_B shall be determined from the curve F_B in Figure 2.

(c) Where the number determined by (a) or (b) above includes a fraction greater than 1/3, it shall be rounded up to the next integer.

**Handed components may be considered to be identical provided at least one component of each hand is inspected. For mechanical couplings, the fasteners (bolts, studs, nuts) in a joint or connection shall be considered as one component, regardless of the number of fasteners in the joint or connection.*

7.5.1.2

The components to be inspected shall be chosen to include those components which are considered to be subject to the most severe conditions.

7.5.1.3

In order to include the most significant indications in the inspection program, as required by Clause 7.4.2.1(e), it may be necessary to select more areas than required by Clause 7.5.1.1.

7.5.1.4

Clause 7.5.1 does not apply to piping supports.

7.5.2 Multi-Unit Power Plant

7.5.2.1
Where there is more than one reactor unit at the power plant, the extent of the periodic inspection on a subsequent unit shall be not less than that for the designated lead unit, unless the requirements of Clause 7.5.2.2 are satisfied.

7.5.2.2
Where the owner can demonstrate to the satisfaction of the regulatory authority that a subsequent unit is essentially identical in design and construction to the designated lead unit and is subjected to similar conditions, the extent of periodic inspection may be reduced for the subsequent unit. The total number of areas to be inspected on identical components in subsequent units shall be not less than the total number inspected on the lead unit multiplied by the following factors:
(a) designated second unit in service: $FR_2 = 0.66$;
(b) designated third unit in service: $FR_3 = 0.39$; and
(c) designated fourth unit in service: $FR_4 = 0.28$.

7.5.2.3
Clause 7.5.2 does not apply to piping supports.

7.6 Inspection Interval

7.6.1 Operating Systems

7.6.1.1
A complete periodic inspection, as required by this Standard, shall be made within a 5-year period, commencing 1 year after the generation of first net power. This inspection should be distributed evenly, as far as it is practical, over the specified period.

7.6.1.2
Subsequent periodic inspections shall be planned for time intervals that do not exceed 1/3 of the design operational life of the plant, or 10 years, whichever is shorter. However, the actual intervals will be determined in consultation with the regulatory authority, based on the results of the preceding inspections and the operational history of the systems. These inspections shall be carried out over the last half of the inspection interval.

7.6.1.3
For a system or component that is subjected to conditions that differ significantly from those contemplated in the design specification, the periodic inspection interval shall be reviewed and, if necessary, the periodic inspection program revised.

7.6.1.4
Where the inspection of a system or component would necessitate the dismantling of equipment, the required periodic inspection should be performed when the equipment has been dismantled for other reasons, eg, maintenance. The detachment of access covers or removal of insulation shall not be considered as dismantling. Any resulting delay in inspection shall not exceed one inspection interval unless evidence (similar component, operating under similar conditions for an equivalent period) can be presented to the regulatory authority to show that no pressure boundary failure mechanisms exist.

7.6.1.5
For multi-unit power plants, the inspection intervals to be used for the inspection program on a given reactor unit shall commence from the generation of first net power by that reactor unit.

7.6.2 Dormant Systems
Components in systems or portions of systems that are
(a) not required to function or to be pressurised under reactor level A conditions, but may be required to function under reactor level B, C, or D conditions; and
(b) required by this Standard to be subjected to periodic inspection
shall be inspected at intervals that correspond to 1/2 of the interval determined by Clause 7.6.1.

7.7 Evaluation of Results
The results from each inspection shall be evaluated according to Clause 8.

7.8 Records
Inspection records of periodic inspections shall comply with the requirements of Clause 11.

8. Evaluation of Inspection Results

8.1 Evaluation

8.1.1
The owner shall be responsible for evaluation of the inspection results.

8.1.2
The results from each inspection shall be evaluated to determine compliance with the acceptance standards specified by Clause 8.2.

8.2 Acceptance Standards and Records

8.2.1 Acceptance Standards — General
The following shall apply:
(a) Indications that show no detectable change has occurred since the previous inspection shall be acceptable.
(b) Where periodic inspection methods are identical to or can be correlated with those used for the manufacturing or construction inspection, the acceptance standards shall not be more stringent than the manufacturing or construction acceptance standards.
(c) Acceptance standards shall be modified if necessary to conform to authorized deviations from manufacturing or construction standards for a specific component.
(d) For cases where the acceptance standards are not given by Clause 8.2, or if given are not relevant, appropriate acceptance standards shall be submitted to the regulatory authority for approval.
(e) Unless otherwise specified, acceptance criteria of the ASME *Boiler and Pressure Vessel Code*, Section XI, IWB-3000 apply.

8.2.2 Visual Inspection
The following shall apply:
(a) Indications that show that a change has occurred since the previous inspection shall be acceptable, provided that the integrity of the component is still adequate and the predicted

deterioration will not seriously reduce the integrity of the component before the next periodic inspection.
(b) The inspection records shall state clearly the nature and extent of any change since the previous inspection.

8.2.3 Surface Inspection

The following shall apply:
(a) Acceptance standards shall be in accordance with Table 1.
(b) Indications having dimensions that exceed 50% of the acceptance level shall be recorded. The record shall include the location, dimensions, orientation, and type of the indication.

8.2.4 Volumetric Inspection

The following shall apply:
(a) Acceptance standards shall be in accordance with Table 1.
(b) Records shall be in accordance with the requirements of Figures 3 and 4 and Clause 11 as applicable.

8.2.5 Integrative Inspection

Acceptance standards and recording criteria for integrative inspection will depend on the technique employed and the characteristic being determined.

The acceptance standards and the recording criteria of the preceding inspection groups shall be employed where applicable. In addition, indications of stress intensities and strains that are greater than the calculated values given in stress analysis reports or other engineering documents, or permitted by the design codes shall be considered unacceptable.

8.2.6 Dimensional Inspection

The following shall apply:
(a) Measurements that show that a change has occurred since the previous inspection shall be acceptable provided that the integrity of the component is still adequate and the predicted deterioration will not seriously reduce the integrity of the component before the next periodic inspection.
(b) Records shall include the measurements and their locations.

8.3 Additional Inspection

When unacceptable indications or significant service induced indications are found during periodic inspection, the following additional inspections shall be made and the results evaluated:
(a) If the indication is in a component of which there is more than one per reactor unit, the area corresponding to that having the indication shall be inspected on additional components. The resulting total inspection shall not be less than twice that of the original sample.
(b) For a multi-unit power plant, the area corresponding to that having the indication shall be inspected on the identical component in each reactor unit at the next reactor cooldown. The period of time permitted to complete this additional inspection shall be based on the accessibility for inspection and the significance of the indication; and in no case shall it exceed 20% of the inspection interval specified in Clause 7.6.

8.4 Disposition

When the result of an inspection does not comply with the acceptance standard, the following shall be completed before returning the component to service:

(a) Notifying the regulatory authority.
(b) Further inspection by other nondestructive methods, where deemed necessary and practical, to assist in determining the nature of the indication.
(c) Additional inspection as specified in Clause 8.3.
(d) Appraisal of the inspection results to determine disposition, ie, acceptance, revised inspection program, repair, or replacement.
(e) Establishment of new acceptance criteria for the deviating component.
(f) Submission of the proposed disposition to the regulatory authority for acceptance.
(g) Obtaining regulatory authority acceptance.

9. Repairs and Replacements

9.1

Components in which defects are revealed by inaugural or periodic inspection shall be repaired or replaced. Such corrective action shall meet the requirements of CSA Standard CAN/CSA-N285.0, Clauses 13.2, 13.3, and 13.4.

Repairs and replacements shall receive inaugural inspection in accordance with Clause 6.

10. Modifications

10.1

Systems and components that are extended, reduced, or otherwise altered after the initial start-up shall be reviewed to establish any change in
(a) the hazard to health and safety;
(b) potential failure consequences;
(c) the extent of systems subject to inspection; and
(d) the inspection category.

10.2

A change in any of the above classifications shall result in the periodic inspection program being amended to ensure that the inspection for revised system complies with the requirements of this Standard.

11. Records

11.1 General Requirements

11.1.1

The permanent records to be maintained shall include
(a) the program document and the subsequent amendments;
(b) records and reports of each inaugural and periodic inspection (see Clauses 11.2 and 11.3);
(c) records of defects discovered by periodic inspection, defect disposition, corrective action taken, details of repairs or replacements, and subsequent inspection; and
(d) all inspection procedures, inspection charts, acceptance standards, and other relevant information.

11.1.2
Permanent records shall be maintained by the owner.

11.2 Inspection Records
The inaugural and periodic inspection records for each inspection area shall include
(a) all pertinent information such as component identification, location and size of inspection areas, inspection method, type of inspection equipment, type of sensor, calibration equipment, sensitivity standards, such that the inspection could be repeated and similar results obtained;
(b) records of inspection results; and
(c) recordings (eg, radiograph, photograph, magnetic tape, chart), except that when the recording shows no indication it need not be kept, provided that a notation to this effect is made in the periodic inspection report.

11.3 Periodic Inspection Reports

11.3.1
An inaugural inspection report shall be produced and sent with the inspection program for the specific reactor unit to the regulatory authority. The report shall list the inaugural inspections performed and any significant indications observed. Confirmatory inspection reports may be submitted after the inaugural inspection report.

11.3.2
After each periodic inspection, the owner shall prepare a report describing the work done, the equipment used, the qualifications of the inspection personnel, those indications that have changed and exceed the reference level with type, size, and location, and those evaluations performed. This report shall be submitted to the regulatory authority within 90 days after completion of that stage of the periodic inspection program.

12. Fuel Channel Pressure Tubes — Supplementary Inspection

12.1 Scope
Clause 12 establishes the requirements for the supplementary periodic inspection of fuel channel pressure tubes manufactured in accordance with CSA standard CAN/CSA-N285.6.1. Nondestructive examination methods defined in Clause 4.1 shall be used.

Surveillance of pressure tube material properties shall be performed in accordance with Clause 12.8.

12.2 Inaugural Inspection
The requirements of Clause 6 shall not apply. The following inspections, and associated records, shall be credited as inaugural inspections:
(a) Manufacturer's volumetric and dimensional inspections as required by CSA Standard CAN/CSA-N285.6.1.
(b) Post installation inspections/dimensional checks.

12.3 Baseline Inspection

12.3.1 Time of Inspection
Baseline inspection shall be performed within a 2-year period, commencing after 7000 equivalent full power hours (EFPH) of operation.

12.3.2 Inspection Sample Size

12.3.2.1 General

Where more than one type of pressure tube material is used in a single unit or multi-unit power plant, the baseline inspection for each type of material shall be determined independently of the other materials. The definition of pressure tube material types shall comply with the specifications presented in CSA Standard N285.6.1.

12.3.2.2 Single-Unit Power Plants

A minimum of 12 pressure tubes shall be selected. Ten of the twelve pressure tubes shall be selected from the high-power region of the reactor. The remaining two pressure tubes shall be selected from the low-power region.

12.3.2.3 Multi-Unit Power Plants

For the designated lead unit in the power plant, the baseline inspection shall be as required in Clause 12.3.2.2. For subsequent units, the inspection sample shall be no less than the following:

(a) designated second unit in service; eight high-power and two low-power pressure tubes;
(b) designated third unit in service; six high-power and two low-power pressure tubes; and
(c) designated fourth and subsequent units in service; four high-power and two low-power pressure tubes.

12.3.3 Extent of Inspection

The baseline inspection shall include

(a) the full volume of the tube including the rolled joint regions;
(b) measurements to determine the pressure tube to calandria tube gap; these may be
  (i) determination of garter spring location, and tube deflection (sag); or
  (ii) pressure tube to calandria tube gap measurements.

The sag or gap measurements shall be separated by no more than 250 mm or one-half fuel bundle length, whichever is less;

(c) internal diameter and tube wall thickness measurements at not less than three equally spaced circumferential positions, with axial spacing separated by no more than 250 mm or one-half fuel bundle length whichever is less; and
(d) measurement(s) to determine the fuel channel position on its bearings.

12.4 Periodic Inspection

12.4.1 Extent of Inspection

The requirements of Clause 12.3.3 shall apply.

12.4.2 Inspection Sample Size

12.4.2.1 General

The tubes selected shall be from the baseline inspection sample. Where more than one type of pressure tube material is used in a single unit or multi-unit power plant, the periodic inspection for each type of material shall be determined independently of the other materials. The definition of pressure tube material types shall comply with the specifications presented in CSA Standard N285.6.1.

12.4.2.2 Single-Unit Power Plants

A minimum of five pressure tubes shall be selected. Four of the five pressure tubes shall be selected from the high-power region of the reactor. The remaining pressure tube shall be selected from the low-power region.

12.4.2.3 Multi-Unit Power Plants

For the designated lead unit in the power plant, the periodic inspection shall be as required in Clause 12.4.2.2. For subsequent units, the inspection sample shall be no less than the following:

(a) designated second unit in service; three high-power and one low-power pressure tubes;
(b) designated third unit in service; two high-power and one low-power pressure tubes; and
(c) designated fourth and subsequent units in service; one high-power and one low-power pressure tube.

12.4.3 Inspection Interval

12.4.3.1 Single-Unit Power Plants

The following shall apply:

(a) A complete periodic inspection, as required by this Standard, shall be made within a 3-year period, commencing 4 years after the generation of the first net power.
(b) Subsequent periodic inspections shall be planned for time intervals that do not exceed 6 years or 1/5 of the component design life, whichever is less. These inspections should be performed over the last half of the inspection interval.

12.4.3.2 Multi-Unit Power Plants

The following shall apply:

(a) For the designated lead unit in the power plant, all requirements of Clause 12.4.3.1 shall apply.
(b) For subsequent units
  (i) the requirements of Clause 12.4.3.1 (a) shall apply; and
  (ii) subsequent periodic inspections shall be planned for time intervals that do not exceed 10 years or 1/3 of the component design life, whichever is less. These inspections should be performed over the last half of the inspection interval.

12.5 Inspection Methods and Procedures

12.5.1 Methods

Inspection methods shall comply with the requirements of Clause 4.1. Volumetric inspection shall be performed using ultrasonic methods, utilizing longitudinal and shear wave techniques. Alternative methods may be used for volumetric inspection with the approval of the regulatory authority.

12.5.2 Procedures

Procedures shall comply with the requirements of Clause 4.2. The capability to detect discontinuities and measure dimensions shall be demonstrated. The reference specimens defined in Clauses 12.5.3 and 12.5.4 shall be used where applicable.

12.5.3 Volumetric Inspection Reference Specimen

A reference specimen shall be made from a pressure tube of the same material and geometry as the pressure tube that is to be inspected, and shall contain the following discontinuities:

(a) Ultrasonic shear wave calibration slots:
  (i) internal longitudinal slot;
  (ii) internal circumferential slot;
  (iii) external longitudinal slot; and
  (iv) external circumferential slot. The dimensions of each discontinuity shall be 6.0 ± 0.5 mm long, 0.15 ± 0.05 mm deep, and 0.15 ± 0.05 mm wide.

(b) Ultrasonic longitudinal wave calibration slots: Three flat-bottomed slots machined from the outside surface. The slots shall be 0.75 ± 0.05 mm wide, 1.5 ± 0.1 mm long, and shall be machined to depths of 15%, 50%, and 85% of the nominal tube wall thickness.

12.5.4 Dimensional Inspection Reference Specimen(s)

The owner shall provide reference specimens which are appropriate to the dimensional measurement techniques employed to satisfy dimensional inspection requirements. Clause 12.5.4, Items (a), (b), and (c) specify only the minimum requirements for these reference specimens. The dimensional reference specimens shall be used to verify the performance and accuracy of the equipment and techniques used to perform the required inspections.

(a) **Sag and/or Gap Determination.** A reference specimen shall be made from a pressure tube and calandria tube (if applicable) of the same material and geometry as the channel to be inspected. The reference specimen shall be manufactured so as to contain dimensions covering the full range of measurements expected during inspection.

(b) **Internal Diameter and Wall Thickness.** A reference specimen shall be made from a pressure tube of the same material and geometry as the pressure tubes to be inspected. The reference specimen shall contain both the minimum and maximum internal diameters, and the minimum and maximum wall thicknesses, specified in the design documentation for the pressure tube to be inspected.

(c) **Fuel Channel Bearing Position Determination.** A reference specimen of the same or equivalent material as the fuel channel component(s) to be measured shall be made. The reference specimen shall be manufactured so as to contain dimensions covering the full range of measurements expected during inspection.

12.6 Inspection Personnel

The requirements of Clause 5 shall apply.

12.7 Evaluation of Results and Disposition

12.7.1 Evaluation

12.7.1.1

The owner shall be responsible for the evaluation of the results of each inspection.

12.7.1.2

The results from each inspection shall be evaluated to determine compliance with the acceptance criteria specified by Clause 12.7.2.

12.7.1.3

The evaluation method used for fitness-for-service assessment, Clause 12.7.2.4, shall have been accepted for use by the regulatory authority prior to it being used.

12.7.2 Acceptance Criteria

12.7.2.1 General

Relevant indications that do not exceed the limits in Clause 12.7.2.2 and show that no detectable change has occurred since the previous inspection shall be acceptable.

12.7.2.2 Volumetric Inspection

The following conditions shall be acceptable:

(a) for ultrasonic shear wave inspection, indications which

(i) are not crack-like; and
(ii) have a response less than that from similarly oriented slots in the reference specimen defined in Clause 12.5.3(a);
(b) for ultrasonic longitudinal wave inspection, indications which are
(i) not crack-like; and
(ii) laminations parallel to the inside tube surface.

12.7.2.3 Dimensional Inspection

Pressure tubes shall be acceptable providing the following conditions are predicted to exist at the next inspection:
(a) the internal diameter is within the maximum specified in design documentation;
(b) the wall thickness is not less than the minimum specified in the design documentation;
(c) the fuel channel remains on its bearings; and
(d) no pressure tube to calandria tube contact.

12.7.2.4 Fitness-for-Service-Assessment

Indications or dimensional conditions that do not comply with the acceptance standards shall be acceptable, provided it has been demonstrated to the regulatory authority that
(a) the integrity of the component is still adequate; and
(b) the predicted deterioration will not seriously reduce the integrity of the component before the next scheduled periodic inspection.

12.7.3 Disposition

When the result of an inspection does not comply with the acceptance standards of Clause 12.7.2, evaluation and further action shall include
(a) notifying the regulatory authority;
(b) further inspection by other nondestructive methods, where necessary, to assist in the determination of the nature (size, shape, location, and orientation) of the indication or dimensional condition;
(c) appraisal of the inspection results, as specified by Clause 12.7.2.4, to determine disposition, ie, acceptance, repair, or replacement;
(d) submission of the proposed disposition to the regulatory authority for acceptance. The disposition shall also include consideration of changes to the extent and frequency of inspection. For multi-unit power plants, consideration shall be given to the inspection of other units; and
(e) obtaining acceptance of the disposition from the regulatory authority prior to returning the reactor to operation.

12.8 Material Surveillance

12.8.1 Initial Material Surveillance

The owner shall be capable of establishing initial fracture toughness and delayed hydride cracking velocity of the tubes selected for material surveillance.

12.8.2 CANDU Lead Unit

12.8.2.1

The CANDU lead unit is defined as the one having pressure tubes with the greatest fast neutron fluence. However, any unit with pressure tubes having fast neutron fluence within 5% of the CANDU lead unit value may be substituted.

12.8.2.2

Inaugural material surveillance shall cover the following activities:
(a) initial material surveillance in accordance with Clause 12.8.1; and
(b) baseline measurements of hydrogen isotope concentration of six pressure tubes within a 2-year period, commencing 9 years after generation of first net power. Should the unit designated for material surveillance change (see Clause 12.8.2.1), then a baseline measurement shall be performed on the newly designated unit. The pressure tubes selected for baseline measurements shall be those subject to the material surveillance over the remaining life of that unit.

12.8.2.3

(a) The following periodic material surveillance shall be performed:
  (i) hydrogen isotope concentration measurement;
  (ii) fracture toughness measurement;
  (iii) delayed hydride cracking velocity measurement.
(b) If a pressure tube is removed to meet the requirements above, the following shall also be performed:
  (i) visual examination of surfaces and determination of garter spring residency; and
  (ii) volumetric examination.

12.8.2.4

The surveillance intervals shall be as follows:
(a) One pressure tube shall be subjected to the periodic material surveillance requirements of Clause 12.8.2.3 within a 2-year period, commencing 12 years after the generation of first net power.
(b) Subsequently, one pressure tube shall be subjected to the requirements of Clause 12.8.2.3 at intervals not exceeding 3 years.
(c) In addition, each pressure tube subjected to the surveillance requirements of Clause 12.8.2.4(b), above, shall be monitored for hydrogen isotope concentration 3 years ± 1 year, prior to its surveillance.

12.8.3 Power Plant Lead Unit

12.8.3.1

The power plant lead unit is defined as the one having pressure tubes with the most EFPH of operation of all the units in the power plant. However, any unit within 7000 EFPH of the lead unit may be substituted.

12.8.3.2

Baseline measurements of hydrogen isotope concentration shall be performed on six pressure tubes within a 2-year period, commencing 9 years after generation of first net power. Should the unit designated for material surveillance change (see Clause 12.8.3.1), then a baseline measurement shall be performed on the newly designated unit. The pressure tubes selected for baseline measurements shall be those subject to the material surveillance over the remaining life of that unit.

12.8.3.3

Periodic hydrogen isotope concentration surveillance shall be performed on three of the six pressure tubes subjected to baseline measurements in Clause 12.8.3.2 above.

12.8.3.4

The surveillance intervals shall be as follows:

(a) One pressure tube shall be subjected to periodic hydrogen isotope concentration measurements within a 2-year period, commencing 12 years after the generation of first net power.

(b) Subsequently, one pressure tube shall be subjected to periodic hydrogen isotope concentration measurements at intervals of 3 years ± 1 year, for the operating life of the reactor.

(c) The scheduling of hydrogen concentration measurements shall be such that each tube will be subjected to measurement only once every three intervals.

12.8.4 Acceptance Criteria and Evaluation Procedures

Acceptance criteria and evaluation procedures for the following measurements shall be submitted to the regulatory authority for acceptance:

(a) hydrogen isotope concentration;

(b) fracture toughness; and

(c) delayed hydride cracking velocity.

Acceptance criteria shall include both absolute and rate of change values.

12.9 Records

12.9.1 General Requirements

Inspection records and the issuance of reports shall comply with the requirements of Clause 11, unless otherwise specified below.

12.9.2 Recording Criteria

12.9.2.1 Volumetric Inspection

The following shall apply:

(a) Specific information, as defined in Clause 12.9.2.1(b), is to be recorded for ultrasonic indications which exhibit any of the following characteristics:

(i) crack-like indications;

(ii) relevant indications equal to or greater than 50% of the corresponding indications from the discontinuities in the reference specimen defined in Clause 12.5.3(a); or

(iii) relevant indications equal to or greater than 50% of the corresponding indications from the discontinuities in the reference specimen defined in Clause 12.5.3(b).

(b) For ultrasonic indications meeting the criteria of Clause 12.9.2.1(a), the following information is to be recorded:

(i) signal characterization;

(ii) dimensions of the indication;

(iii) axial and circumferential location of the indication; and

(iv) signal amplitude with respect to discontinuities in the reference specimen.

(c) When alternative volumetric inspection methods (ie, other than ultrasonic inspection) are used, then the recording criteria shall be submitted to the regulatory authority and approval obtained prior to commencing inspection.

12.9.2.2 Dimensional Inspection

All dimensional data collected shall be recorded to permit comparison with previous and future inspections.

12.9.2.3 Material Surveillance

All data collected shall be recorded to permit comparison with previous and future inspections.

12.9.3 Reporting Criteria

12.9.3.1 Volumetric Inspection

Data recorded in accordance with Clause 12.9.2.1 shall be reported.

12.9.3.2 Dimensional Inspection

The following shall be reported:

(a) The maximum internal diameter, the location of the maximum internal diameter, maximum change in internal diameter since previous inspection, and rate of change in diameter.

(b) The minimum wall thickness, the location of the minimum wall thickness, maximum change in wall thickness since previous inspection, and rate of change in wall thickness.

(c) The minimum pressure tube to calandria tube gap, the location of the minimum gap, maximum change in gap since previous inspection, and rate of change in gap.

(d) The most extreme bearing position, and the predicted rate of change.

12.9.3.3 Material Surveillance

The following shall apply:

(a) The owner shall submit to the regulatory authority a report describing the results of the surveillance performed and the subsequent evaluation(s) to demonstrate compliance with the acceptance criteria of Clause 12.8.4.

(b) The results of hydrogen isotope concentration measurements shall be reported to the regulatory authority within 120 days after completion of that stage of surveillance.

(c) All other surveillance results shall be reported to the regulatory authority within 1 year of commencement of surveillance activities.

13. Fuel Channel Feeder Pipes — Supplementary Inspection

13.1 Scope

Clause 13 establishes the requirements for the supplementary periodic inspection of fuel channel feeder pipes.

13.2 Inaugural Inspection

The following shall apply:

(a) A visual inaugural inspection of all feeder pipes and all supports shall be performed on pre-operational reactor units and a record made of any observations arising from the inspection relating to the pressure-retaining integrity of these components; and

(b) Wall thickness measurements on a minimum of 20 feeder pipes shall be performed on all pre-operational reactor units. The inspection areas shall be chosen from those which are accessible and which are likely to experience the greatest reduction in wall thickness.

13.3 Periodic Inspection

13.3.1 Inspections

The following shall apply:

(a) A direct or remote general visual inspection of readily accessible feeder piping, piping

supports, and fret sleeves shall be carried out. Disassembly of supports or fret sleeves is not required. The use of remote inspection equipment is permitted; and
(b) Direct or remote visual inspection of indications recorded during the inaugural inspection of Clause 13.2.(a); and
(c) Wall thickness measurements shall be performed on feeder pipes as required below.

13.3.2 Single Unit Power Plants

A minimum of 10 feeder pipes selected from the inaugural inspection sample shall be subjected to periodic inspection.

13.3.3 Multi-Unit Power Plants

For periodic inspection of multi-unit power plants, the inspection sample size on the designated first unit in service shall be as required in Clause 13.3.2 above.

For subsequent units, the inspection sample size shall be no less than the following:
(a) designated second unit in service: seven feeders;
(b) designated third unit in service: four feeders; and
(c) designated fourth unit in service: three feeders.

13.3.4 Inspection Interval

The following shall apply:
(a) The scheduling of inspections shall comply with the requirements of Clause 7.6.
(b) When it can be demonstrated from inspection results to the satisfaction of the regulatory authority that non-erosive and non-corrosive conditions exist, no further wall thickness measurement is required.

13.4 Evaluation of Results and Disposition

The evaluation and disposition shall comply with Clause 8, except that acceptance and recording criteria shall comply with Clause 13.5.

13.5 Acceptance and Recording Criteria

The following shall apply:
(a) indications of reduction from the initial feeder pipe wall thickness of 20% or greater shall be recorded and reported;
(b) indications of reduction from the initial feeder pipe wall thickness of 40% or greater shall be submitted to the regulatory authority for disposition; and
(c) for visual inspection, the provisions of Clauses 8.2.1 and 8.2.2 shall apply.

14. Steam Generator Tubes — Supplementary Inspection

14.1 Scope

Clause 14 establishes the requirements for the supplementary periodic inspection of tubes in steam generators and tubes in separate preheater vessels.

14.2 Sample Inspection

Tubes to be inspected for inaugural and periodic inspection shall be selected from two categories: specific and random.

14.2.1 Specific Sample

The following shall apply:

(a) The specific sample shall include tubes from regions considered to be at higher risk of in-service degradation.

(b) For degradation mechanisms reliably detected by standard bobbin coil eddy current inspection, the full length of each tube in a specific sample shall be inspected, to the extent practicable.

(c) For degradation mechanisms not reliably detected by standard bobbin coil eddy current inspection,

(i) specialized NDE probes and techniques shall be validated and used to provide information for comparison;

(ii) where a postulated degradation mechanism is only applicable to specific section(s) of the tube, then only such section(s) require inspection.

14.2.2 Random Sample

For the random sample, the following shall apply:

(a) the number of tubes in the random sample shall be at least 50% of the required total;

(b) tubes to be inspected shall be chosen to cover all areas of the steam generator, with the exception of those covered by full length inspection under Clause 14.2.1; and

(c) to the extent practicable, the full length of each selected tube shall be inspected.

14.3 Inaugural Inspection

The following shall apply:

(a) in each reactor unit, a minimum of 25% of the tubes in each steam generator and a minimum of 25% of the tubes in each separate preheater shall be subject to inaugural inspection;

(b) tubes to be inspected shall be selected in accordance with Clauses 14.2.1 and 14.2.2;

(c) inaugural inspection shall be performed either

(i) after the primary side hydrostatic pressure test but before start-up of the reactor; or

(ii) before the primary side hydrostatic test, provided that a confirmatory inspection of 10% of the tubes, as required by (d) below, is performed after the primary side hydrostatic pressure test and the results indicate no significant change;

(d) confirmatory inspection shall employ the method(s) used for the inaugural inspection and the confirmatory sample shall include tubes with the most significant indications detected previously.

14.4 Periodic Inspection — Steam Generators

14.4.1 Single-Unit Power Plants

The following shall apply:

(a) A minimum of 10% of the total number of tubes in one steam generator, chosen from those in the inaugural sample, shall be subjected to periodic inspection.

(b) Tubes to be inspected shall be selected in accordance with Clauses 14.2.1 and 14.2.2.

(c) The tubes and support structure shall be visually inspected on the secondary side of one steam generator.

(d) A section of one tube in a deposit region shall be removed from one steam generator for metallurgical examination.

14.4.2 Multi-Unit Power Plants

14.4.2.1 Designated Lead Unit

The following shall apply:
(a) The owner shall designate the lead unit based on service and operating conditions. The requirements of Clause 14.4.1 shall apply to the lead unit.
(b) Where the owner can demonstrate to the satisfaction of the regulatory authority that subsequent units are essentially identical in design and construction to the designated lead unit and are subjected to similar conditions, the periodic inspection may be reduced to 2% of the total number of tubes in one steam generator.

14.4.3 Inspection Interval

14.4.3.1 Single-Unit Power Plants

Periodic inspections shall be planned for the time intervals which do not exceed 5 years or 1/5 of the component design life, whichever is less. These inspections should be performed over the last half of the inspection interval.

14.4.3.2 Multi-Unit Power Plants

The following shall apply:
(a) For the designated lead unit, the requirements of Clause 14.4.3.1 shall apply.
(b) Where the owner can demonstrate to the satisfaction of the regulatory authority that subsequent units are essentially identical in design and construction to the designated lead unit and are subjected to similar conditions, the following intervals may apply:
(i) a complete periodic inspection, as required by this Standard, shall be completed within a 3-year period, commencing 2 years after the generation of the first net power; and
(ii) subsequent periodic inspections shall be planned for time intervals that do not exceed 10 years or 1/3 of the component design life, whichever is less. These inspections shall be performed over the last half of the inspection interval.

14.4.3.3 Altered Intervals

If steam generator tubes are subjected to conditions that differ significantly from those contemplated in the design specification, the periodic inspection sample size and inspection interval shall be reviewed and, if necessary, the periodic inspection program revised.

14.5 Periodic Inspection — Separate Preheater

14.5.1 Single-Unit Power Plants

14.5.1.1

For single-unit power plants, one separate preheater shall be inspected.

14.5.1.2

The following shall apply:
(a) A minimum 2% of the total number of tubes in one preheater shall be subjected to periodic inspection.
(b) The inspection shall be made within a 3-year period, commencing 2 years after the generation of the first net power.
(c) Subsequent periodic inspections shall be planned for time intervals that do not exceed 10 years or 1/3 of the component design life, whichever is less. These inspections shall be performed over the last half of the inspection interval.

14.5.2 Multi-Unit Power Plants

Tubes in one separate preheater shall be inspected in the designated lead unit only. Requirements of Clause 14.5.1.2 shall apply.

14.6 Inspection Methods and Procedures

14.6.1 Methods

Volumetric inspection methods (eg, bobbin coil or specialized eddy current, ultrasonic) shall be used.

14.6.2 Procedures

Procedures shall comply with the requirements of Clause 4.2.

14.6.3 Calibration and Reference Specimens

14.6.3.1 General Requirements

Calibration and reference specimens shall be manufactured from lengths of tubing of the same nominal size, material type (chemical composition and heat treatment), and method of manufacture as those to be examined.

For standard bobbin probe inspection, the calibration specimen of Clause 14.6.3.2 shall be used to ensure that equipment response is acceptable and results are comparable.

When the calibration specimen of Clause 14.6.3.2 is not adequate for the detection or evaluation of existing or anticipated flaws, then the reference specimen specified in Clause 14.6.3.3 shall be used.

14.6.3.2 Calibration Specimen

The calibration specimen shall be that defined by the ASME *Boiler and Pressure Vessel Code*, Section V, or may be replaced with a specimen containing the following discontinuities, provided it can be demonstrated equivalent or better when using the inspection procedure:

(a) external circumferential groove 3 mm wide, concentric flat bottomed and having a depth equal to 10% of the nominal wall thickness;

(b) internal circumferential groove, 3 mm wide eccentric (90 degree arc) flat bottomed and having depth equal to 10% of the nominal wall thickness;

(c) through wall hole of 1.5 mm diameter.

14.6.3.3 Reference Specimen

A reference specimen shall contain discontinuities and conditions (eg, representative tube supports) that are comparable to existing or anticipated flaws and conditions. It shall be used to demonstrate the ability of the inspection system when the calibration specimen of Clause 14.6.3.2 is not adequate for the detection or evaluation of such flaws.

This reference specimen may be used to set up the inspection equipment if the standard calibration specimen of Clause 14.6.3.2 is inadequate.

14.7 Inspection Personnel

The requirements given in Clause 5 shall apply.

14.8 Evaluation of Results and Disposition

14.8.1 Evaluation

14.8.1.1
The owner shall be responsible for the evaluation of the results of each inspection.

14.8.1.2
The results from each inspection shall be evaluated to determine compliance with the acceptance criteria specified by Clause 14.8.2.

14.8.1.3
The evaluation method used for fitness-for-service assessment, Clause 14.8.2.3, shall have been accepted for use by the regulatory authority prior to it being used.

14.8.2 Acceptance Criteria

14.8.2.1 General
Relevant indications that do not exceed the acceptance criteria below, or show that no detectable change has occurred since the previous inspection, shall be acceptable.

14.8.2.2 Volumetric Examination
Indications of degradation, where predicted wall loss will not exceed 40% of the nominal wall thickness prior to the next inspection, shall be acceptable.

14.8.2.3 Visual Examination
Observations which show that a change has occurred since the previous inspection shall be acceptable, provided that the integrity of the tube(s) and their support structure is still adequate and the predicted deterioration will not seriously reduce the integrity of the tubes before the next periodic inspection.

14.8.2.4 Fitness-for-Service-Assessment
Indications that do not comply with the acceptance criteria shall be acceptable, provided it has been demonstrated to the regulatory authority that
(a) the integrity of the tube(s) and support structure is still adequate; and
(b) the predicted deterioration will not seriously reduce their integrity before the next scheduled periodic inspection.

14.8.3 Disposition
When the result of an inspection does not comply with the acceptance criteria of Clause 14.8.2, evaluation and further action shall include
(a) notifying the regulatory authority;
(b) further inspection by other methods, where necessary, to assist in the determination of the nature (size, shape, location, and orientation) of the indication or condition;
(c) appraisal of the inspection results, as specified by Clause 14.8.2.4, to determine disposition, ie, acceptance, repair, or replacement;
(d) submission of the proposed disposition to the regulatory authority for acceptance. The disposition shall also include consideration of changes to the extent and frequency of inspection. For multi-unit power plants, consideration shall be given to the inspection of other units; and
(e) obtaining acceptance of the disposition from the regulatory authority prior to returning the reactor to operation.

14.8.4 Additional Inspection

14.8.4.1 Flaws Exceeding Acceptance Criteria

The following shall apply:

(a) Additional inspection shall include tubes surrounding those with indications, which do not satisfy the acceptance criteria of Clause 14.8.2, to bound the degradation. As a minimum, the additional inspection shall include all tubes whose centre lines are located within a radius of 2.5 times the tube spacing from the centre line of the affected tube.

(b) Consideration shall be given to additional inspection of similarly located tubes in other steam generators in the reactor unit.

14.8.4.2 Reportable Flaws

For flaws reportable by Clause 14.9.3, an assessment of the degradation type and sampling extent shall be made to determine additional inspection requirements.

14.9 Records

14.9.1 General Requirements

Inspection records and the issuance of reports shall comply with the requirements of Clause 11, unless otherwise specified below.

14.9.2 Recording Criteria

14.9.2.1 Purpose

All data collected shall be recorded to permit comparison with data from previous and future inspections.

14.9.2.2 Volumetric Examination

The following conditions shall be recorded:

(a) all relevant indications;

(b) conditions which affect access and/or assessment.

14.9.2.3 Visual Examination

The inspection records shall state clearly the nature and extent of any change since the previous inspection.

14.9.3 Reporting

14.9.3.1 Volumetric Examination

The following inspection results shall be reported:

(a) indications in excess of 20% of tube wall thickness;

(b) indications which on reinspection show detectable change.

14.9.3.2 Visual Examination

All significant changes in the observed condition of the tubes and support structure shall be reported.

14.9.3.3 Metallurgical Examination

The results of the examination performed and the subsequent evaluation(s) shall be reported to the regulatory authority within 1 year.

Table 1
Designated Inspection Methods and Acceptance Criteria

Component to be Inspected	Inspection Method(s) to be Utilised (1)	Acceptance Criteria Reference Clause (2)	Applicable ASME XI Reference
Piping and Nozzle Welds	Visual	8.2.2	
	and		
	Volumetric		
	Ultrasonic Method (1)	8.2.4.a Figures 3&4	
	Radiographic Method (1)	8.2.4.a	Table IWB-3514-4
	and		
	Surface (4)	8.2.3	Table IWB-3514-4
	or		
	Integrative	8.2.5	
Vessel Welds	Visual	8.2.2	
	and		
	Volumetric		
	Ultrasonic Method (1)	8.2.4.a(i)Figures 3&4	
	Radiographic Method (1)	8.2.4.a(i)	Table IWB-3510-3
	and		
	Surface (4)	8.2.3	Table IWB-3510-3
	or		
	Integrative	8.2.5	
Mechanical Couplings	**Bolting < or = 25.4 mm (1 inch)**		
Bolts, Studs, and Nuts	Visual	8.2.2	
Ligaments between threaded stud holes	Visual	8.2.2	
Bushings	Visual	8.2.2	
Other components	Visual	8.2.2	
	and		
	Surface	8.2.3	
	or		
	Volumetric	8.2.4	
	or		
	Integrative	8.2.5	
Mechanical Couplings	**Bolting > 25.4 mm (1 inch)**		
Bolts and Studs	Visual	8.2.2	
	and		
	Surface	8.2.3	IWB-3515.1
	or		
	Volumetric	8.2.4	IWB-3515.2
	or		
	Integrative	8.2.5	
Nuts	Visual	8.2.2	
Ligaments between threaded stud holes	Visual	8.2.2	
	and		
	Surface	8.2.1.d	
	or		
	Volumetric	8.2.1.d	
	or		
	Integrative	8.2.5	
Bushings	Visual	8.2.2	
Other Components	Visual	8.2.2	
	and		
	Surface	8.2.1.d	
	or		
	Volumetric	8.2.1.d	
	or		
	Integrative	8.2.5	

(Continued)

Table 1 (Concluded)

Component to be Inspected	Inspection Method(s) to be Utilised (1)	Acceptance Criteria Reference Clause (2)	Applicable ASME XI Reference
Pumps and Valves			
1. Welds	Visual	8.2.2	
	and		
	Volumetric	8.2.4.a	
	Ultrasonic Method (1)		Table-IWB-3518.1 or 2
	Radiographic Method (1)		Table-IWB-3518.1 or 2
	and		
	Surface (4)	8.2.1.d	Table-IWB-3518.1 or 2
	or		
	Integrative	8.2.5	
2. Internal surfaces	Visual	8.2.2	
	and		
	Surface (3)	8.2.1.d	
Supports			
1. Supports	Visual	8.2.2	
2. Component attachment welds	Visual	8.2.2	
	and		
	Surface	8.2.1.d	
	or		
	Volumetric	8.2.1.d	
	or		
	Integrative	8.2.5	
Rotating machinery	Visual	8.2.2	
	and		
	Surface	8.2.1.d	
	or		
	Volumetric	8.2.1.d	
	or		
	Integrative	8.2.5	
All components			
For corrosion	Dimensional	8.2.6	
For erosion	Dimensional	8.2.6	

Notes:
(1) *Radiographic examination, a volumetric method, may be used instead of ultrasonic examination only when it is not possible to perform ultrasonic examination. Regulatory authority approval must be obtained in such cases.*
(2) *Clauses 8.1 and 8.2 are applicable in all cases.*
(3) *This inspection is required only for materials subject to stress corrosion cracking.*
(4) *Surface method need only be used to inspect the external surface of the inspection area when 1/3 t internal surface volumetric inspection is used.*

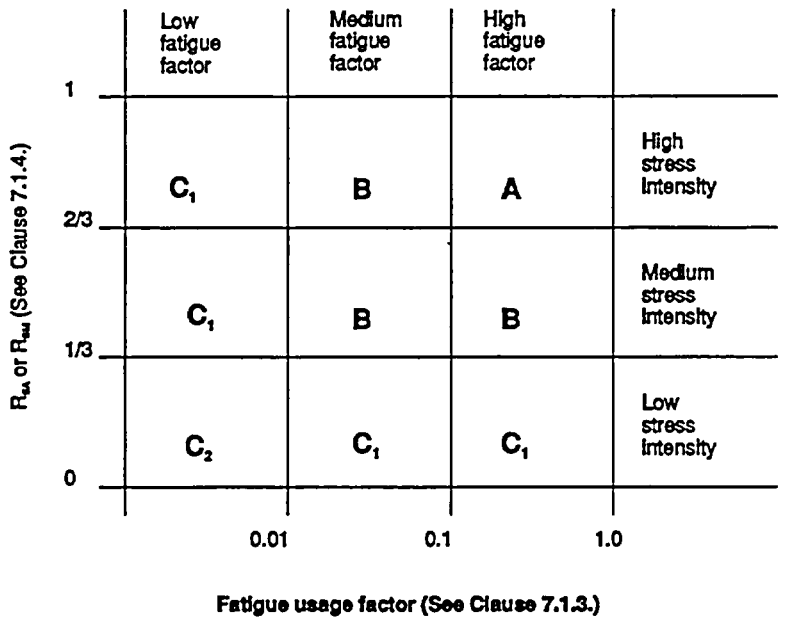


Figure 1(a)
Determination of Inspection Category for Medium Failure Size
(See Clause 7.1.5.)

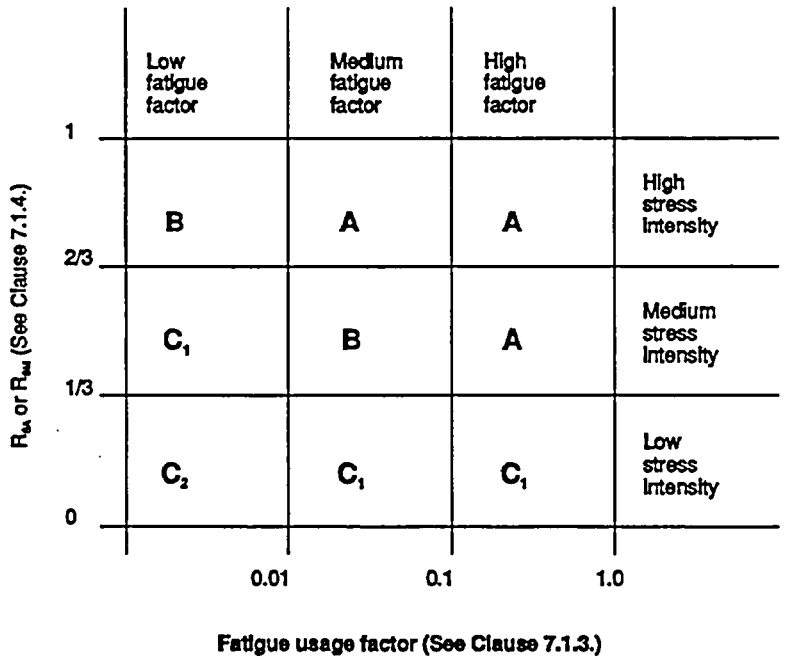


Figure 1(b)
Determination of Inspection Category for Large Failure Size
(See Clause 7.1.5.)

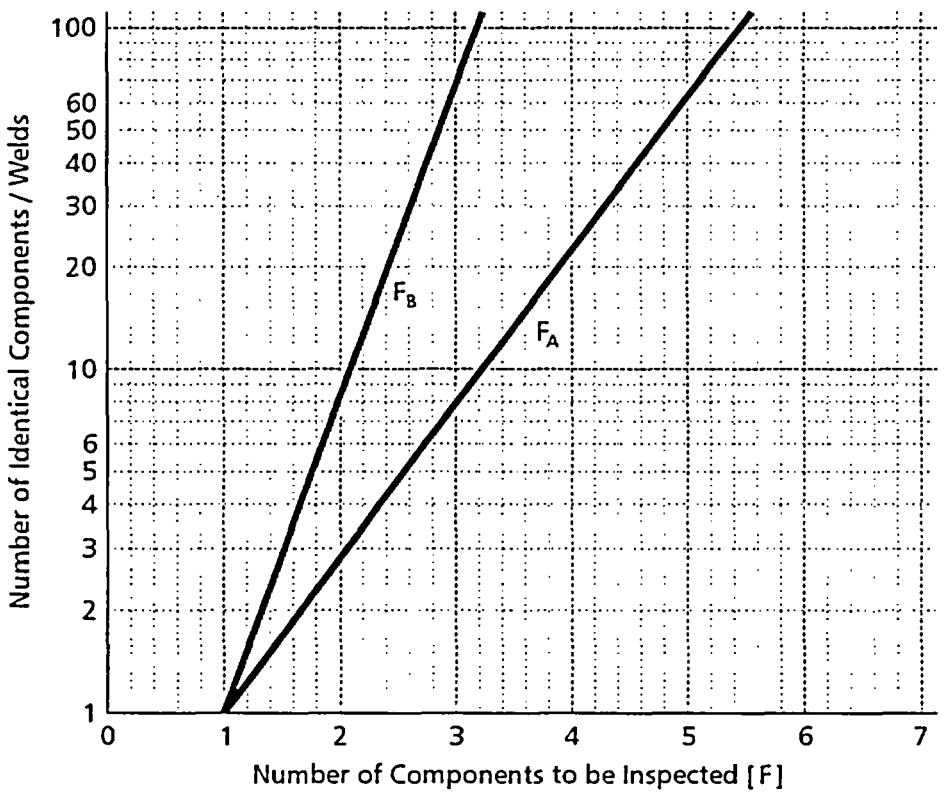
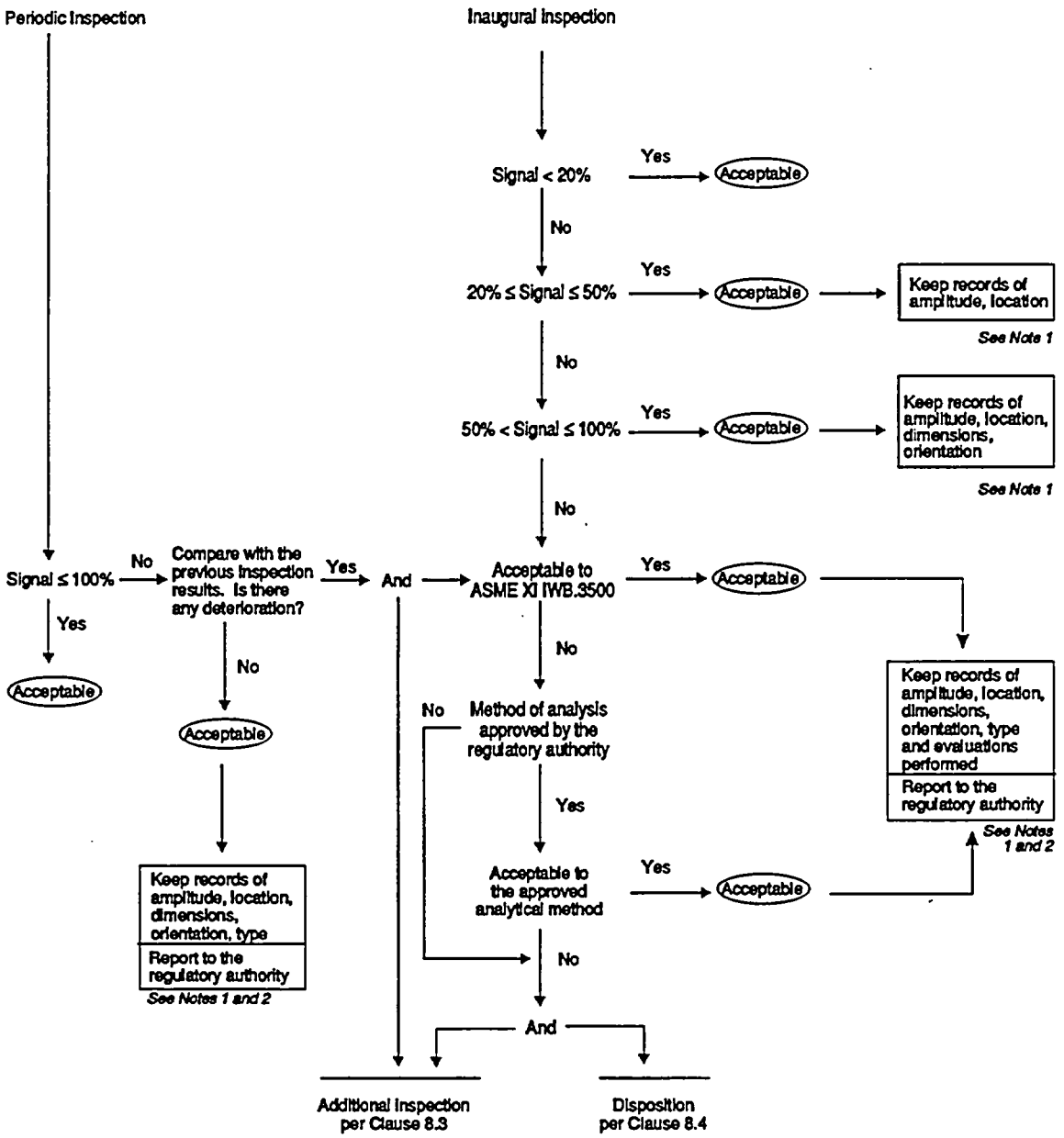


Figure 2
Inspection Sample for Identical Components/Welds

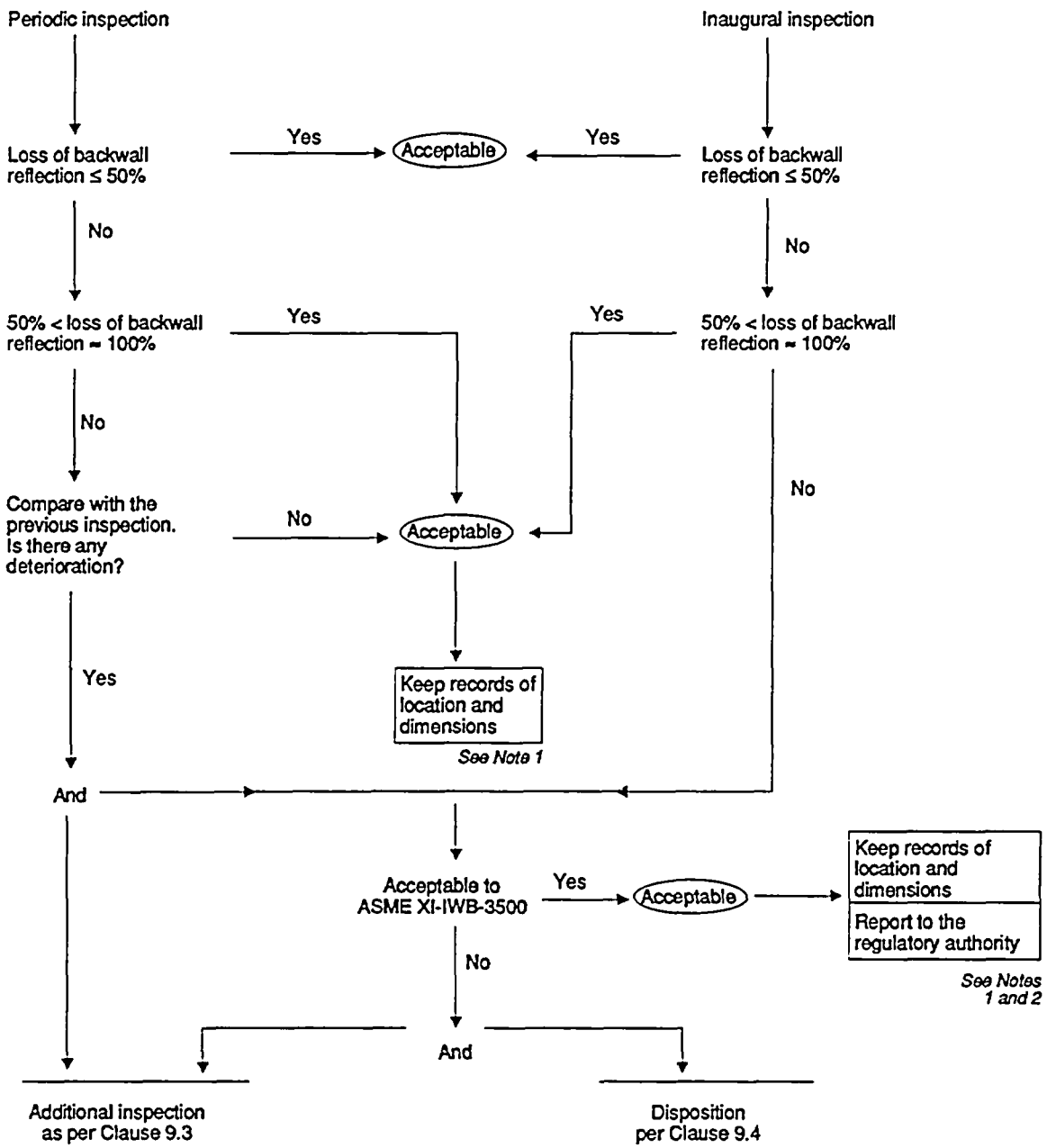


Notes:

(1) *Inspection records shall meet the requirements of Clauses 11.1 and 11.2.*

(2) *Inspection records shall meet the requirements of Clause 11.3.*

Figure 3
Acceptance Standards, Recording and Reporting, Criteria for Weld Inspection Area: Ultrasonic Inspection Method
(Not Applicable to Bolts and Nuts)



Notes:

(1) *Inspection records shall meet the requirements of Clauses 11.1 and 11.2.*

(2) *Inspection records shall meet the requirements of Clause 11.3.*

Figure 4
Acceptance Standards, Recording and Reporting, Criteria for Lamination Scan: Ultrasonic Inspection Method
(Not Applicable to Bolts and Nuts)

Appendix A
Summary of Inspection Logic — Guide for Periodic Inspection

Note: *This Appendix is not a mandatory part of this Standard.*

Scope	Conditions	Hazard	Failure	Systems	System limits	Duty factor	Inspection category	Inspection
Clause 3.1.1	Clause 3.1.1	Clause 3.2	Clause 3.3.1	Clause 3.3.1	Clause 3.3.2	Clause 7.1.2, 7.1.3, 7.1.4	Clause 7.1.5	Clause 7.4, 7.5

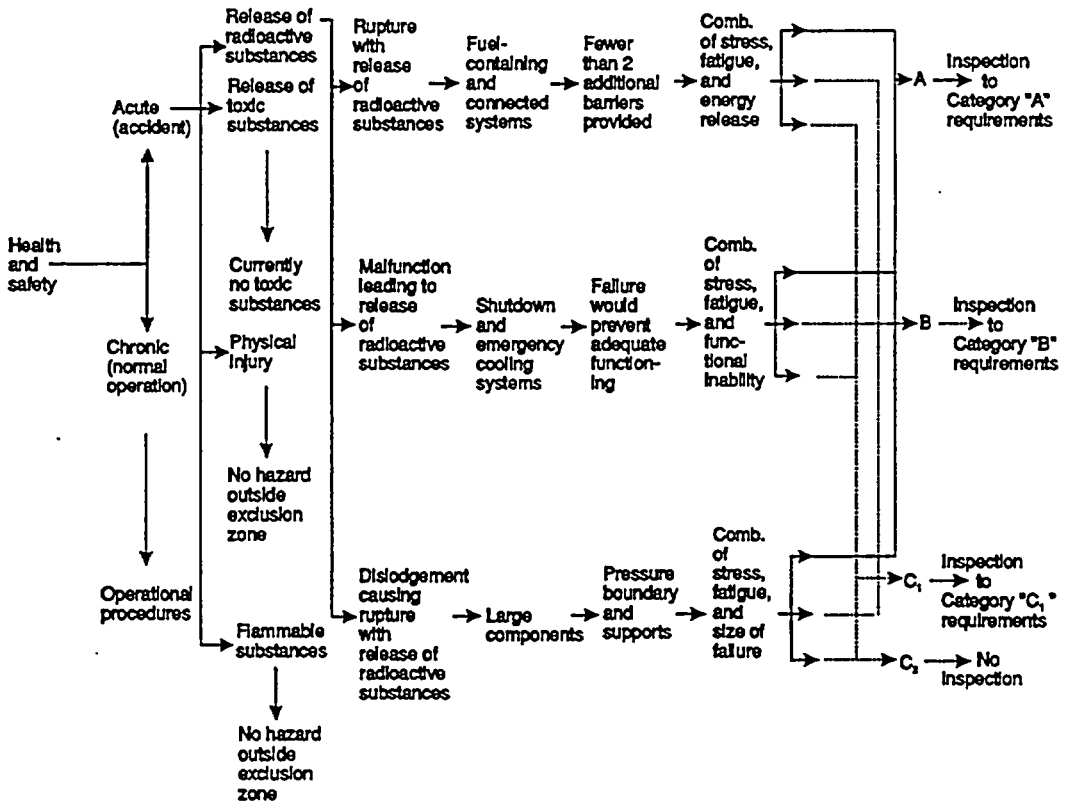


Figure A1
Summary of Inspection Logic

Proposal for Change

To help our volunteer members to assess proposals to change requirements we recommend that each proposal for change be submitted in writing and identify the
(a) Standard number;
(b) Clause number;
(c) proposed wording of the Clause (requirement, test, or pass/fail criterion) using mandatory language and underlining those words changed from the existing Clause (if applicable); and
(d) rationale for the change, including all supporting data necessary to be considered.

The proposal should be submitted to the Standards Administrator at least one month prior to the next meeting of the Committee. It is CSA Committee practice that only those proposals sent out to members prior to a meeting can be the subject of discussion and action. This is to allow the members time to consider the proposal and to do any research they may feel necessary.

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From: _____

Affiliation: _____

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Proposed change:

(Use reverse and additional pages as required.)

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_____	_____	x _____	= _____	– _____	+ _____	= _____	+ _____	+ _____	= _____
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Les normes CSA reflètent le consensus de producteurs et d'usagers de partout au pays, au nombre desquels se trouvent des fabricants, des consommateurs, des détaillants et des représentants de syndicats, de corps professionnels et d'agences gouvernementales. L'utilisation des normes CSA est très répandue dans l'industrie et le commerce, et leur adoption à divers ordres de législation, tant municipal et provincial que fédéral, est chose courante, particulièrement dans les domaines de la santé, de la sécurité, du bâtiment, de la construction et de l'environnement.

Les Canadiens d'un bout à l'autre du pays témoignent de leur appui au travail de normalisation mené par la CSA en participant bénévolement aux travaux des comités de la CSA et en appuyant ses objectifs par leurs cotisations de membres de soutien. Les quelque 7000 volontaires faisant partie des comités et les 2000 membres de soutien constituent l'ensemble des membres de la CSA parmi lesquels ses administrateurs sont choisis. Les cotisations des membres de soutien représentent une source importante de revenu pour les services de soutien à la normalisation volontaire.

L'Association offre des services de certification et de mise à l'essai qui appuient et complètent ses activités dans le domaine de l'élaboration de normes. De manière à assurer l'intégrité de son processus de certification, l'Association procède de façon régulière et continue à l'examen et à l'inspection des produits portant la marque CSA.

Outre son siège social et ses laboratoires à Etobicoke, la CSA possède des bureaux régionaux dans des centres vitaux partout au Canada, de même que des agences d'inspection et d'essai dans huit pays. Depuis 1919, l'Association a parfait les connaissances techniques qui lui permettent de remplir sa mission d'entreprise, à savoir la CSA est un organisme de services indépendant dont la mission est d'offrir une tribune libre et efficace pour la réalisation d'activités facilitant l'échange de biens et de services par l'intermédiaire de services de normalisation de certification et autres, pour répondre aux besoins de nos clients, tant à l'échelle nationale qu'internationale.

The Canadian Standards Association (CSA), under whose auspices this National Standard has been produced, was chartered in 1919 and accredited by the Standards Council of Canada to the National Standards system in 1973. It is a not-for-profit, nonstatutory, voluntary membership association engaged in standards development and certification activities.

CSA standards reflect a national consensus of producers and users — including manufacturers, consumers, retailers, unions and professional organizations, and governmental agencies. The standards are used widely by industry and commerce and often adopted by municipal, provincial, and federal governments in their regulations, particularly in the fields of health, safety, building and construction, and the environment.

Individuals, companies, and associations across Canada indicate their support for CSA's standards development by volunteering their time and skills to CSA Committee work and supporting the Association's objectives through sustaining memberships. The more than 7000 committee volunteers and the 2000 sustaining memberships together form CSA's total membership from which its Directors are chosen. Sustaining memberships represent a major source of income for CSA's standards development activities.

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General Instruction No. 1

CAN/CSA-N285.6 Series-88
March 1988

CSA Standard CAN/CSA-N285.6 Series-88, *Material Standards for Reactor Components for CANDU Nuclear Power Plants,* consists of **93** pages, each dated **March 1988.**

This Standard, like all CSA Standards, is subject to periodic review, and amendments in the form of replacement pages may be issued from time to time; such pages will be mailed automatically to those purchasers who complete and return the attached card.* Some Standards require frequent revision between editions, whereas others require none at all. It is planned to issue new editions of the Standard, regardless of the amount of revision, at intervals not greater than 5 years. Except in unusual circumstances, replacement pages will not be issued during the last year of that edition.

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Prepared by
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Preface

This is the first edition of the CAN/CSA-N285.6 Series, *Material Standards for Reactor Components for CANDU Nuclear Power Plants.*

The first eight Standards in this Series prescribe requirements for alloys for use as reactor components. The objectives of these Standards are to

(a) provide reference design data for these alloys and component conditions not included in the *ASME Pressure Vessel Code*;

(b) specify requirements for fabrication of the components used for constructional purposes;

(c) specify the required properties of the materials in the forms specified; and

(d) reference the inspection requirements imposed during manufacture of these components.

The Standards, by virtue of the effects of the reactor core environment, necessarily specify in detail the manufacturing, inspection, and design values required. The Committee responsible for these Standards recognizes the need to accommodate technological developments and changes in requirements that may necessitate changes or additions to the existing Standards.

The ninth Standard prescribes requirements for materials for component supports.

It is the intention of the Committee to facilitate improvements to the Standards by a periodic review of issued Standards. Suggestions for improvements will be accepted at any time; these will be recorded by the Committee and acted upon at an appropriate time. The Committee will perform a technical review of any comprehensively documented submission supporting the use of an alloy or alloy modification not at present specified. Such an alloy must have a practical application and such a submission must contain sufficient experimental and test data to provide confidence in its use. The submission must contain adequate test data to develop design stress intensity and other physical property values against temperature. In addition, the Committee will review submissions supporting the use of material specified herein at design conditions other than those specified, and provide a response for interpretations of any aspects of these Standards.

Users of these Standards are reminded that the design, manufacture, construction, commissioning, operation, and decommissioning of nuclear facilities in Canada are subject to the provisions of the Atomic Energy Control Act and Regulations. Thus, requirements in addition to those specified in these Standards may be imposed by the Atomic Energy Control Board.

This Series was prepared by the Materials Subcommittee and approved by the CSA Technical Committee on CANDU Nuclear Power Plant Components under the jurisdiction of the Steering Committee on Nuclear Standards, and was formally approved by these Committees. It has been approved as a National Standard of Canada by the Standards Council of Canada.

March 1988

Notes:

(1) *The terms "examination" and "inspection" are used interchangeably in this Standard and do not have the distinct meanings defined in CSA Standard CAN3-N285.0.*

(2) *Use of the masculine gender in this Standard is not meant to exclude the feminine gender when applied to persons. Similarly, use of the singular does not exclude the plural (and vice versa) when the sense allows.*

(3) *Although the intended primary application of this Standard is stated in its Scope, it is important to note that it remains the responsibility of the user of the Standard to judge its suitability for his particular purpose.*
(4) *CSA Standards are subject to periodic review, and suggestions for their improvement will be referred to the appropriate committee.*
(5) *All enquiries regarding this Standard, including requests for interpretation, should be addressed to Canadian Standards Association, Standards Division, 178 Rexdale Boulevard, Rexdale, Ontario M9W 1R3.*

Requests for interpretation should
(a) define the problem, making reference to the specific clause, and, where appropriate, include an illustrative sketch;
(b) provide an explanation of circumstances surrounding the actual field condition; and
(c) be phrased where possible to permit a specific "yes" or "no" answer.

Interpretations are published in CSA Information Update. *For subscription details and a free sample copy, write to CSA Marketing or telephone (416) 747-4019.*

National Standard of Canada CAN/CSA-N285.6.6-88

Inspection Criteria for Zirconium Alloys

Prepared by
Canadian Standards Association

Approved by
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Reference Publications

This Series refers to the following publications and the year dates shown indicate the latest issues available at the time of printing:

CSA Standards

CAN3-G40.20-M87,
General Requirements for Rolled or Welded Structural Quality Steel;

CAN3-G40.21-M87,
Structural Quality Steels;

N285.0-M81,
General Requirements for Pressure Retaining Systems and Components in CANDU Nuclear Power Plants.

ASTM Standards

A370-77,
Standard Methods and Definitions for Mechanical Testing of Steel Products;

B350-80,
Specification for Zirconium and Zirconium Alloy Ingots for Nuclear Application;

B351-79,
Specification for Hot-Rolled and Cold-Rolled Finished Zirconium and Zirconium Alloy Bars, Rod, and Wire for Nuclear Application;

D129-64 (Reapproved 1978),
Test for Sulfur in Petroleum Products (General Bomb Method);

D512-80,
Standard Test Methods for Chloride Ion in Water;

D808-81,
Test for Chlorine in New and Used Petroleum Products (Bomb Method);

D1179-80,
Test for Fluoride Ion in Water;

E8-81,
Standard Methods for Tension Testing of Metallic Materials;

E10-78,
Standard Test Method for Brinell Hardness of Metallic Materials;

E18-79,
Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials;

E21-79,
Standard Recommended Practice for Elevated Temperature Tension Tests of Metallic Materials;

E92-72 (Reapproved 1977),
Standard Test Method for Vickers Hardness of Metallic Materials;

E112-81,
Standard Methods for Estimating the Average Grain Size of Metals;

E165-80,
Recommended Practice for Liquid Penetrant Inspection Method;

E381-79,
Method of Microetch Testing, Inspection and Rating Steel Products Comprising Bars, Billets, Blooms and Forgings;

G2-80,
Standard Practice for Aqueous Corrosion Testing of Samples of Zirconium Alloys.

ASME* Boiler and Pressure Vessel Code—1986

Section II, Material Specifications
Part A, Ferrous Materials;
Part C, Welding Rods, Electrodes and Filler Metals;

Section III, Nuclear Power Plant Components, Division 1,
Subsection NB, Class 1 Components;
Subsection NCA, General Requirements and Appendices;
Subsection NF, Component Supports;

Section V,
Nondestructive Examination;

Section IX,
Welding and Brazing Qualifications.

**American Society of Mechanical Engineers.*

CAN/CSA-N285.6.1-88
Seamless Zirconium Alloy Tubing for Fuel Channels

1. Scope

1.1

This Standard covers the requirements for the fabrication and properties of seamless zirconium alloy tubing suitable for use as the in-core portions of fuel channels of a CANDU reactor.

2. Definitions

2.1

The following definitions apply in this Standard:

Extrusion—a process of producing a tube shell from a forged trepanned billet at a temperature above 750°C.

The front end of an extrusion of subsequently worked tube—the end that emerges first from the extrusion die.

Drawings mentioned in the Standard—those detailed in pertinent tendering and contract documents.

Reactor-grade sponge—sponge with a low hafnium content that has passed through a sorting procedure to remove contaminants such as oxygen- and nitrogen-rich material. Reactor-grade scrap is remelt material suitably qualified by source control and analysis.

3. Ingot Requirements

3.1 Ingot Preparation

Zirconium sponge of reactor grade and, if desired, identified reactor-grade scrap of compatible material and the necessary alloying ingredients shall be formed into suitable electrodes. All welding used in the production of electrodes shall be by the electron beam or another process that does not involve risk of contamination by electrode or shield material. Master alloy additions shall be in a form that does not inhibit solution in the melt.

Melting shall be in a consumable-electrode, vacuum-arc melting furnace. The first melt ingots shall be remelted under similar conditions to form the ingot. Melting practice shall be such as to ensure adequate homogeneity of the ingot and the absence of defects, compounds, and segregation detrimental to subsequent fabrication or serviceability.

3.2 Ingot Conditioning

The ingot shall be conditioned by turning or grinding, or both, to remove surface defects, and to disclose and remove segregation and porosity.

3.3 Ingot Identification

Each ingot shall be metal-die-stamped on the top with the manufacturer's ingot number.

3.4 Ingot Chemical Analysis

3.4.1 Sampling of Ingot

The ingot shall be sampled at least once for every 800 to 1000 kg of ingot weight. These samples shall be taken uniformly along the length of the ingot so as to sample the top, bottom, and points in between. Additional samples shall be taken in areas where segregation is suspected.

The analysis shall comply with the requirements of Clause 3.4.2. The procedures for the analysis shall be submitted to, and accepted by, the purchaser before the analysis is made. The results of each analysis shall be reported for each element specified.

3.4.2 Chemical Composition

The requirements for chemical composition shall be as given in Table 1.1 and in accordance with the requirements of Tables 1.2 and 1.3

3.5 Ingot Hardness

The hardness of the ingot shall be determined as described in ASTM Standard E10, at the positions where samples are taken for chemical analysis. The hardness shall not exceed 187 BHN for alloy R60802 and 220 BHN for alloy R60901.

Table 1.1
Chemical Composition of Zirconium Alloys

Elements alloyed to zirconium	Alloy R60802	Alloy R60901 (Zr-Nb)
Tin	1.20-1.70 wt%	
Iron	0.07-0.20 wt%	
Chromium	0.05-0.15 wt%	
Nickel	0.03-0.08 wt%	
Niobium		2.40-2.80 wt %
Carbon	150- 400 ppm	
Oxygen	900-1400 ppm	900-1200 ppm
Total Fe + Cr + Ni	0.18-0.38 wt%	

Table 1.2
Permitted Impurities in Zirconium Alloys

Elements	Alloy R60802 ppm, max.	Alloy R60901 ppm, max.
Aluminum	75	75
Boron	0.5	0.5
Cadmium	0.5	0.5
Carbon	—	270
Chromium	—	200
Cobalt	20	20
Copper	50	50
Hafnium	50	50
Hydrogen	20	20
Iron	—	1500
Lead	130	130
Magnesium	20	20
Manganese	50	50
Molybdenum	50	50
Nickel	—	70
Niobium	100	—
Nitrogen	65	65
Silicon	120	120
Tantalum	200	200
Tin	—	100
Titanium	50	50
Tungsten	100	100
Uranium	3.5	3.5
Vanadium	50	50

Table 1.3
Permissible Variation in Product Analysis

Element	Permissible variations from specified range, %, or maximum
Tin	0.050
Iron	0.020
Chromium	0.010
Chromium and iron and nickel	0.020
Niobium	0.050
Oxygen	0.007
All others	0.002 or 20%, whichever is smaller

3.6 Ingot NDE

The ingot shall be ultrasonically examined to meet the requirements of Clause 8.6.2. Procedures describing such examinations shall be submitted to, and accepted by, the purchaser prior to examination.

4. Billet Requirements

4.1 Process Requirements

The extrusion billets shall be fabricated by hot-forging of the ingots. The process of billet fabrication may include an intermediate beta quench. The forging and heat-treatment conditions shall be specified by the contractor and accepted by the purchaser as conforming with established practice. The conditions so specified shall not be changed during the course of a contract without the written consent of the purchaser.

4.2 Identification

Each billet shall be identified by metal-die-stamping on the bottom end. This identification shall relate the billet to the ingot from which it was produced and its position relative to the top of the ingot. The identification shall also show whether the ingot was forged in one piece or divided into sections.

4.3 Billet Check Analysis

A check analysis shall be made on one billet per ingot to confirm the type analysis of the material. The procedures used shall be approved by the purchaser.

4.4 Billet Conditioning

All surfaces of the hollow billet shall be conditioned to disclose and remove forging defects by the removal of metal by machining or machining and pickling to a depth of at least 3.5 mm. Selective removal of isolated surface defects may be done up to a depth of 5 mm, providing the surrounding surface is blended at least 25 mm in all directions.

4.5 Billet NDE

Each billet shall be ultrasonically examined to the requirements of Clause 8.6.3. Procedures describing such examination shall be submitted to, and approved by, the purchaser prior to examination. Following removal of any defect by blending to the requirements of Clause 4.4, that area shall be reinspected by nondestructive techniques approved by the purchaser to prove that the defect had been removed.

5. Extrusion Requirements

5.1 Process Requirements

The billets shall be extruded to shells at a reduction ratio, extrusion speed, extrusion temperature, and cooling rate to conform with established practice. These parameters shall not be changed during the course of a contract without the written consent of the purchaser.

The fabricator shall ensure that heating times and temperatures of the billets prior to extrusion are similar from billet to billet within practical limits. As

a general rule, billets shall be extruded so that the end closest to the top of the ingot is extruded first. Exceptions to this procedure should be clearly identified in the tube records.

5.2 Extruded Shell Conditioning

The extruded shell shall be conditioned prior to further treatment to remove all traces of cladding or other surface contamination resulting from the extrusion operation. Such conditioning may be by chemical or mechanical means. Localized removal of material shall be permitted, but such areas shall be blended out, noted on the inspection sheet, and subjected to close examination during tube examination.

6. Tube Requirements

6.1 Tube-Process Requirements

6.1.1 General

The tubes covered by this specification may be fabricated to

(a) condition CW by cold drawing or pilgering of the extruded hollows without any expansion operations or annealing treatments; or

(b) condition HT (for alloy R60901), by cold drawing following a quench from the $\alpha + \beta$ range as described below.

For condition HT, the tubes may be cold-reduced prior to heat treatment to the extent deemed necessary by the manufacturer. The processing of the tube may include a surface removal operation prior to the final stress-relief/aging treatment.

6.1.2 Identification and Traceability

Each tube shall be identified with a serial number. Records shall be kept that identify the tube with the original ingot from which it was produced, and with the processing history of the tube. The serial numbering system shall provide a unique number for each tube, and shall be subject to approval by the purchaser.

The serial number shall be metal-die-stamped on the back-end face of the tube so that the numbers read in the clockwise direction. The metal-die-stamps shall be low-stress stamps.

6.1.3 Condition CW

Tubes of alloy R60802 composition shall be cold-worked between 15 and 25%; tubes of R60901 composition shall be between 20 and 30%. Cold work is defined as the reduction in cross-sectional area during the cold-working operation subsequent to extrusion.

6.1.4 Condition HT

For tubes of R60901 composition specified to be fabricated in the HT condition, the following treatment shall be carried out.

The tubes shall be solution heat-treated by furnace-heating to 870 ± 15°C. Heating shall take place with the tubes filled with inert gas and the bottom ends sealed and top ends closed with a loose fitting plug to allow expanding gas to escape. The heating rate shall be as rapid as possible to minimize oxidation. The furnace atmosphere shall be such as to prevent hydrogen contamination of the tubes. The tubes shall be held at temperature for a minimum of 5 min. For each measuring point, the furnace temperature, tube temperature, and the time at temperature shall be recorded. A furnace survey and calibration shall be carried out at least once every 6 months.

The tubes shall be lowered at a rate of 300 mm/s minimum into a water-quenching bath that does not exceed 50°C. If other water temperatures or lowering rates are used, the combination shall be such as to ensure a quenching rate exceeding 100°C/s. The direction of quenching (eg, back end first) shall be standardized and reported. Water temperature and lowering rates shall also be recorded.

Prior to proceeding with the intermediate cold draw, approximately 0.1 mm of material shall be removed from the outside surface and 0.05 mm from the inside surface. The effectiveness of the solution heat-treatment shall be determined by metallographic examination and hardness tests as follows:

(a) A transverse metallographic specimen shall be prepared from each end of each tube. After suitable preparation and etching, the specimens shall be examined while magnified 1000 times. If heat treatment has been performed successfully, the microstructure will consist of martensitic α, with at least 10% uniformly dispersed globular primary α. The presence of an α phase precipitated in the grain boundary is not permissible.

(b) Hardness tests shall be performed on the prepared metallographic specimens. If solution heat-treatment has been performed successfully, the hardness will exceed 240 VHN, using Test Method E92-72.

If either test indicates unsuccessful heat-treatment, further work on the tube or tubes may only be performed after approval by the purchaser. Heat-treatment shall not be repeated without prior written agreement of the purchaser.

After solution heat-treatment and prior to aging, the tubes shall be cold-reduced a minimum of 10% and a maximum of 15% as defined by reduction of area during the cold-drawing operation.

6.1.5 Surface Removal

Following cold-working, the tubes shall be conditioned by the removal by chemical or mechanical means of 0.05 mm from the inside surface.

6.1.6 Stress Relief/Aging

The tubes in condition CW shall then be stress-relieved at 400 ± 15°C for 24 h in a steam atmosphere. At the option of the purchaser, a prior vacuum stress relief at a temperature higher than 400°C may be specified. Tubes in condition HT shall be aged at 500 ± 15°C for 24 h in an inert atmosphere. They shall then be cleaned to remove oxidation and then given a 400 ± 15°C stress relief for 24 h in a steam atmosphere.

6.2 Dimensional Correction

Following cold-working and after stress-relieving or aging, the tubes may be straightened and ovality corrected by approved procedures to meet the dimensional requirements of the drawings specified on the tendering documents.

6.3 Hydrostatic Pressure Test

Each tube shall be hydrostatically pressurized to 27.5 MPa for a minimum of 30 s at 20°C following a procedure as described in Clause 8.4. This pressure is intended to apply a fibre stress of approximately 60% of the room-temperature longitudinal yield stress. The tube shall exhibit no leaks during the test and the pressure drop during the test shall not exceed 1.0 MPa. The tube shall be visually examined after testing for evidence of distortion caused by the pressure.

6.4 Tube Hardness

A hardness test to the requirements of Clause 8.9 shall be made on each end of each tube and the results shall be reported.

6.5 Quality Requirements

6.5.1 General

The contractor shall meet the requirements of the quality Standards specified in the contractual documents.

6.5.2 Soundness

The tubes shall be examined for defects by ultrasonic methods to the requirements outlined in Clause 8.6.4 of this Standard. The inspection procedures shall be submitted to, and accepted by, the purchaser prior to inspection.

6.5.3 Surface Quality

All surface contaminations resulting from the final draw and other operations shall be removed. The method of removal is subject to the acceptance by the purchaser.

The internal and external surfaces of the cold-drawn tube prior to stress relief/aging shall be given a visual examination to the requirements of Clause 3.3 of CSA Standard CAN/CSA-N285.6.6.

The internal and external surfaces of the tubes shall be free from dirt, oil, grease, lubricants, or other contaminants. The cleaning procedures and tests for determining cleanliness shall be subject to acceptance by the purchaser. Cleaning materials shall have a maximum of 250 ppm halogen and 1% by weight of sulphur and shall be so certified.

After stress relief/aging, a visual examination shall meet the requirements of Clause 3.4 of CSA Standard CAN/CSA-N285.6.6.

6.5.4 Dimensional Inspection

The contractor shall perform dimensional inspection to the extent required to ensure compliance with the requirements of the drawing. Inspection procedures incorporating the requirements of Clause 8.7 shall be supplied to, and accepted by, the purchaser.

7. Tube Material Requirements

7.1 Chemical Composition

The chemical composition of the completed tubes shall meet the basic requirements stated in Clause 3.4.2 and shall be sample-checked to the requirements of Clause 8.2.

7.2 Mechanical Properties

The material in each of the finished tubes shall have the minimum longitudinal tensile strength properties specified in Table 1.4 when tested at 300°C in accordance with Clause 8.3.

Table 1.4
Minimum Tensile Strength Properties

	Alloy R60802	Alloy R60901 Condition CW			Alloy R60901 Condition HT	
		(a)	(b)	(c)	(a)	(b)
Ultimate tensile strength MPa	330	435	460	480	540	540
0.2% Yield strength MPa	270	325	330	330	450	395
Elongation, %, in 4.5 (cross-sectional area)$^{1/2}$	12.0	12.0	12.0	12.0	10.0	10.0

7.3 Corrosion Resistance

A sample from each tube shall be tested to a procedure meeting the requirements of Clause 8.5 of this Standard. The corrosion-tested coupons from alloy R60802 shall show a uniform, black, lustrous oxide film and have a weight gain of not more than 22 mg/dm^2. The colour shall be compared to that of standard coupons to ensure uniformity of assessment of colour.

The corrosion-tested coupons from alloy R60901 tubes shall show a uniform, dark greyish blue, oxide film and have a weight gain of not more than 35 mg/dm^2.

If the coupons fail to satisfy the above requirements, an additional two coupons may be taken and tested for 14 d in 400°C steam at 10.3 ± 0.7 MPa. After the test the coupons shall have a uniform, lustrous oxide and a weight gain of not more than 38 mg/dm^2 for alloy R60802 and 90 mg/dm^2 for alloy R60901. If either of the repeat coupons fails to satisfy the requirements, a retest may be performed with the consent of the purchaser. If the retest fails, the tube shall be rejected.

8. Inspection, Tests, and Examination

8.1 General

The contractor shall be responsible for, shall provide for, and shall perform all the inspection, examination, and testing specified herein. The inspection, examination, and testing shall be conducted in a manner satisfactory to, and shall be subject to the acceptance of, the purchaser.

The product shall be carefully examined during manufacture and after completion to determine its conformance with this Standard with respect to material, workmanship, finish, identification, and dimensions.

Surveillance by the purchaser or his authorized representative shall not in any way relieve the contractor of the inspection duties called for herein.

A limited number of spot checks by, or on behalf of, the purchaser shall be considered part of normal inspection procedures and within the scope of the contract without extra charge. The contractor shall provide all reasonable tooling and personnel necessary to conduct such spot checks, and shall give assistance as required.

The purchaser shall have the right to specify additional inspection or testing as deemed necessary, with the additional cost of such work borne by the purchaser.

8.2 Chemical Analysis

A sample for chemical analysis shall be taken adjacent to the tube end representative of the top of each ingot and adjacent to the tube end representative of the bottom of each ingot. The method of sampling and the method of analysis shall be by accepted techniques with determinations of hydrogen, nitrogen, oxygen and niobium. The results shall meet the requirements of Clause 7.1.

8.3 Tensile Testing

Samples shall be taken from tubes at the following positions and stages of manufacture:

(a) For a tube fabricated to the CW condition, a sample shall be taken from the front end after cold

drawing. From this sample, one longitudinal test specimen shall be machined to the dimensions of Figure 1.1. Specimens shall be heat treated for 24 h at 400 ± 5°C and then tested at 300 ± 1.5°C to a procedure meeting the requirements of ASTM Standard E21.

(b) For a tube fabricated to the HT condition, samples shall be taken from the front and back ends of the tube following final aging. From these samples, longitudinal test specimens shall be machined to the dimensions of Figure 1.1. They shall be tested at 300 ± 1.5°C to a procedure meeting the requirements of ASTM Standard E21.

The test specimen, with an extensometer attached for measuring the extension of the gauge length only, shall be held at 300 + 1.5°C test temperature for a minimum of 5 min prior to load application. The strain rate shall be 0.005 ± 0.002 mm/mm of the extensometer gauge length per minute during loading up to the 0.2% yield stress point. The free cross-head speed may then be increased to 1.2 mm/min to failure.

The results of the tensile test shall meet the requirements of Clause 7.2 of this Standard.

Should the above specimens not meet the requirements of Clause 7.2 two additional test specimens may be taken from the same sample of the tube. These shall, if necessary, be heat-treated and tested in the same manner as the first specimen. If the average of three test results satisfies the requirements of Clause 7.2, the tube shall be acceptable. If the average does not meet the requirements, the contractor may, at the discretion of the purchaser, obtain another sample at a position farther away from the tube end. Two specimens from this sample shall be tested as described above and the results of these tests shall both meet the requirements of Clause 7.2.

For tubes accepted on the first specimen test results, the remaining tube samples from which the additional two specimens should have been taken shall be suitably marked and identified according to the tube numbers. These shall be retained by the contractor until the end of the contract and then discarded. Similarly, the material remaining from the samples supplied for retesting shall also be retained by the contractor.

8.4 Hydrostatic Pressure Test

Following final drawing, grinding, and straightening, each tube shall be hydrostatically pressure-tested in accordance with Clause 6.3. If this test is found to result in handling damage to the surface of the tubes, it may be done prior to the final grinding pass, providing not more than 5% of the wall is removed from the wall thickness after the test.

The tube shall be isolated from the pressurizing equipment during the time at maximum pressure, and a record of pressure against time produced for each test.

8.5 Corrosion Test

One coupon with minimum dimensions of 25 × 50 mm shall be taken from the front end of each cold-worked tube. The coupon shall be degreased, pickled, cleaned, and corrosion-tested to a procedure meeting the requirements of ASTM Standard G2. The pickling bath composition and temperature shall be as specified for the relevant alloy. The coupons shall be exposed to steam at 400°C and 10.3 MPa for 72 h.

8.6 Nondestructive Examination

8.6.1 General

All personnel performing nondestructive examination shall be qualified to the requirements of Clause 2 of CSA Standard CAN/CSA-N285.6.6.

8.6.2 Ingot Examination

Each ingot shall be examined ultrasonically to the requirements of Clause 6.2 of CSA Standard CAN/CSA-N285.6.6.

8.6.3 Billet Examination

Each finished billet shall be ultrasonically examined to the requirements of Clause 6.3 of CSA Standard CAN/CSA-N285.6.6.

8.6.4 Tube Examination

The tube shall be ultrasonically examined after cold working, hydrostatic testing, and grinding, and after the final stress relief or aging operation.

The examination shall conform to the requirements of Clause 6.5 of CSA Standard CAN/CSA-N285.6.6.

8.7 Dimensional Inspection of Tubes

The contractor shall perform dimensional inspection to the extent required to ensure compliance with the requirements of the drawing. In addition to any other dimensional measurement, the internal diameter shall be measured and recorded at positions specified on the drawing along the length of each tube on diameters spaced 45° apart.

Wall thickness shall be measured by the ultrasonic, continuous, helical scanning technique, with a pitch no greater than 20 mm. The measuring accuracy

shall be within 0.025 mm. In addition, the wall thickness shall be measured at two sections 75 mm from each end of the tube. Eight measurements 45° apart shall be made at each section. The reference temperature for dimensional inspection shall be 20°C.

8.8 Tube Weighing

Each tube shall be weighed and the weights shall be recorded to the nearest 0.025 kg. The weigh scales used shall be calibrated in divisions not larger than 0.025 kg. The accuracy of the weigh scales shall be checked using calibrated weights before and after each period of use and shall be within ± 0.025 kg.

8.9 Tube-Hardness Test

For tubes in the CW condition, hardness test samples shall be taken from material adjacent to each end of the tube after the hydrostatic test and final machining operation. The Rockwell "C" hardness shall be measured at positions 120° apart on the outside surface of each sample in accordance with ASTM Standard E18. The backup material shall be radiused to the minimum specified tube inside diameter. All three hardness values at each end of the tube shall be reported.

For tubes in the HT condition, hardness shall be measured on the outside surface within 12.5 mm of the end of the tube. The testing shall measure hardness at positions 120° apart to a procedure accepted by the purchaser.

8.10 Inspection, Examination, or Test Failures

In the event of the failure of any ingot, billet, tube, or test sample to meet an inspection or test requirement specified herein, the contractor shall notify the purchaser and must obtain authorization before additional test or repair work is undertaken on material intended to be presented to the purchaser as meeting the requirements of this Standard.

If the repair is likely to affect the results of tests or work previously completed, appropriate reinspection and retesting shall be carried out.

The quality control procedure to ensure a satisfactory repair shall be subject to acceptance by the purchaser.

A record shall be maintained for all rejected tubes with details of the reasons for rejection, in a form approved by the purchaser.

9. Quality Control Records

9.1 Contents of File

The contractor shall maintain a complete file of records for all pressure tubes, billets, and ingots. The records shall contain manufacturing, inspection, examination, and test data, including the procedures, specifications, and drawings used. All records shall be fully identified by pertinent identification numbers. All closely related data such as qualifications and approval of procedures and equipment, data on required items, records of deviations, and concession requests and approvals shall also be included in the record file.

In addition, the contractor shall maintain an inspection, examination, and test checklist for each pressure tube.

9.2 Maintenance of and Access to Records

All records specified in Clause 9.1 shall be filed and maintained in a manner that will allow access by the purchaser or his authorized representatives to specific information contained therein at any time during manufacture. The contractor shall take such steps as may be required to provide suitable protection of all records from deterioration or damage.

10. Packaging and Shipment

10.1

The tubes shall be sealed in polyethylene sleeves and protected by suitable packaging to prevent damage, corrosion, and entry of all foreign materials. Suitable means shall be provided for mechanical handling of individual tubes outside the shipping crate.

Packaging and shipping procedures must be submitted to, and accepted, by the purchaser.

National Standard of Canada CAN/CSA-N285.6.1-88

Seamless Zirconium Alloy Tubing for Fuel Channels

Prepared by
Canadian Standards Association

Approved by
Standards Council of Canada

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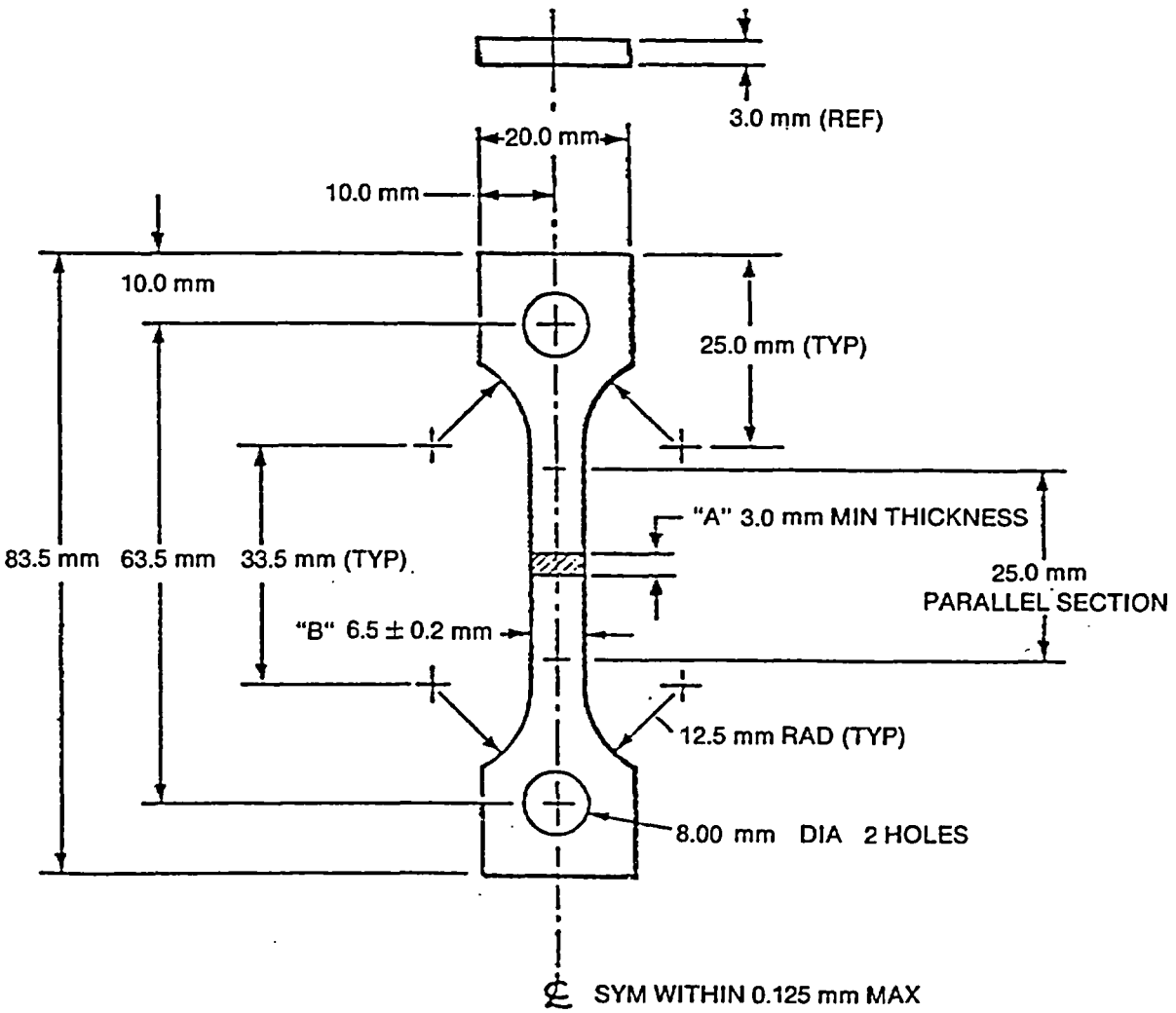

Notes:

(1) *Specimen shall be suitable for use in a* 25 mm *extensometer.*
(2) *Gauge length for elongation to failure shall be* L = 4.5 (cross-sectional area)$^{1/2}$
(3) *Dimensions "A" and "B" shall be constant* ± 0.025 mm *over parallel section.*
(4) *Identification marks shall be in the gripper area and not in the parallel section.*
(5) *Dimensional tolerances: one place of decimals* ± 0.25 mm; *two places of decimals* ± 0.125 mm.
(6) *Dimensions "A" and "B" shall be recorded to the nearest* 0.0025 mm. *The cross-sectional area is to be rounded to the next higher* 0.0025 mm^2.

Figure 1.1
Tensile Test Specimen

National Standard of Canada CAN/CSA-N285.6.2-88

Seamless Zirconium Alloy Tubing for Reactivity Control Rods

Prepared by
Canadian Standards Association

Approved by
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CAN/CSA-N285.6.2-88
Seamless Zironium Alloy Tubing for Reactivity Control Rods

1. Scope

1.1

This Standard covers the requirements for the fabrication and properties of seamless zirconium alloy tubing to be used in reactivity control rods. Generally, this Standard applies to tubing with a diameter to wall thickness ratio of less than 80:1.

2. Definitions

2.1

The following definitions apply in this Standard:

Ovality—the difference between the maximum and minimum outside diameters measured in any one cross-section, exclusive of accepted local irregularities.

Out of straightness—the maximum gap between the surface of the tube and a straight edge of 3 m length held in a plane through the axis of the tube and touching it in two or more places.

Radial bow—the maximum radial deviation from an imaginary axis joining the centres of the ends (or specified reference planes) of the tube (generally determined as half of the TIR measurement).

Total indicated runout (TIR.)—the maximum variation measured when a tube is rotated through 360° about its axis, exclusive of acceptable local irregularities.

3. Manufacturing Requirements

3.1

The tube shall be seamless, produced by a process incorporating extrusion, cold-working, and annealing. The tubes shall be supplied in the annealed condition.

4. Ingot Requirements

4.1 Ingot Preparation

Zirconium sponge of reactor grade and, if desired, identified reactor-grade scrap of compatible material and the necessary alloying ingredients shall be formed into suitable electrodes. All welding used in the production of electrodes shall be by the electron beam or another process that does not involve risk of contamination by electrode or shield materials. Master alloy additions shall be in a form that does not inhibit solution in the melt.

Melting shall be in a consumable-electrode, vacuum-arc melting furnace. The first melt ingots shall be remelted under similar conditions to form the ingot. Melting practice shall be such as to ensure adequate homogeneity of the ingot and the absence of defects, compounds, or segregation detrimental to subsequent fabrication or serviceability.

4.2 Ingot Conditioning

The ingot shall be conditioned by turning or grinding, or both, to remove surface defects, and to disclose and remove segregation and porosity.

4.3 Ingot Identification

Each ingot shall be metal-die-stamped on the top with the manufacturer's ingot number.

4.4 Ingot Chemical Analysis

4.4.1 Sampling of Ingot

The ingot shall be sampled at least once for every 800 to 1000 kg of ingot weight. These samples shall be taken uniformly along the length of the ingot so as to sample the top, bottom, and points in between. Additional samples shall be taken in areas where segregation is suspected.

The analysis shall comply with the requirements of Clauses 4.4.2 and 4.4.3. The procedures for the analysis shall be submitted to, and accepted by, the purchaser before analysis is made. The results of each analysis shall be reported for each element specified.

4.4.2 Chemical Composition

The requirements for chemical composition shall be as given in Table 2.1 and in accordance with the requirements of Tables 2.2 and 2.3.

Table 2.1
Chemical Composition of Zirconium Alloys

Elements alloyed to zirconium	Alloy R60802 (Zr-2)	Alloy R60804 (Zr-4)
Tin	1.20–1.70 wt%	1.20–1.70 wt%
Iron	0.07–0.20 wt%	0.18–0.24 wt%
Chromium	0.05–0.15 wt%	0.07–0.13 wt%
Nickel	0.03–0.15 wt%	—
Niobium	—	—
Carbon	80– 440 ppm	80– 440 ppm
Oxygen	900–1600 ppm	900–1600 ppm
Total Fe + Cr + Ni	0.18–0.38 wt%	0.28–0.37 wt%

Table 2.2
Permitted Impurities for Zirconium Alloys

Permitted impurities	Alloy R60802 ppm, max.	Alloy R60804 ppm, max.
Aluminum	75	75
Boron	0.5	0.5
Cadmium	0.5	0.5
Carbon	—	—
Chromium	—	—
Cobalt	20	20
Copper	50	50
Hafnium	50	50
Hydrogen	20	20
Iron	—	—
Lead	130	130
Magnesium	20	20
Manganese	50	50
Molybdenum	50	50
Nickel	—	70
Niobium	100	100
Nitrogen	65	65
Silicon	120	120
Tantalum	200	200
Tin	—	—
Titanium	50	50
Tungsten	100	100
Uranium	3.5	3.5
Vanadium	50	50

Table 2.3
Permissible Variation in Product Analysis

Element	Permissible variations from specified range, %, or maximum
Tin	0.050
Iron	0.020
Chromium	0.010
Chromium and iron and nickel	0.020
Niobium	0.050
Oxygen	0.007
All others	0.002 or 20%, whichever is smaller

4.5 Ingot Hardness

The hardness of the ingot shall be determined as described in ASTM Standard E10, at the positions where samples are taken for chemical analysis. The hardness shall not exceed 187 BHN for either alloy R60802 or alloy R60804.

4.6 Ingot NDE

The ingot shall be ultrasonically examined to, and meet the requirements of Clause 6.7. Procedures describing such examinations shall be submitted to, and accepted by, the purchaser prior to examination.

5. Product Requirements

5.1 Annealing

The tubing shall be annealed at a temperature between 650°C and 750°C in a vacuum at an equilibrium absolute pressure not exceeding 0.15 Pa. The temperature and duration of annealing shall be such that the average grain size of the parent material shall not exceed ASTM Micrograin size No. 7 when determined in accordance with ASTM Standard E112. Prior to annealing, the tubes shall be cleaned in such a manner as to ensure freedom from contamination that might affect resistance to corrosion.

5.2 Identification

All tubes shall be identifiable with the ingot from which they are produced and with the processing history of the billet.

5.3 Hydrostatic Test

Each tube shall be hydrostatically pressurized to a pressure sufficient to induce a fibre stress equivalent to 50% of the room-temperature, minimum longitudinal yield stress for a minimum of 30 s at 20°C. The tube shall exhibit no leakage during the test and the pressure drop shall not exceed 1.0 MPa. The tube shall be visually examined after testing for evidence of distortion caused by the pressure.

5.4 Chemical Composition

The ingot analysis shall be accepted as the chemical analysis of the tubing except for hydrogen and nitrogen contents, which shall be determined from samples from the finished tube, as detailed in Clause 6.2, and shall be as follows:

Hydrogen	25 ppm (max.)
Nitrogen	80 ppm (max.)

5.5 Mechanical Properties

The material in the finished tubes shall show the room-temperature mechanical properties listed as follows, when tested in accordance with Clause 6.3 of this Standard:

Ultimate tensile strength	415 MPa (min.)
0.2% yield stress	240 MPa (min.)
Elongation in 50 mm	20% (min.)

5.6 Corrosion Resistance

A sample from the finished tubes shall be tested for corrosion resistance to a procedure meeting the requirements of Clause 6.4.

After the exposure, the specimens shall show a uniform, black, lustrous oxide film and have a weight gain of no more than 22 mg/dm^2.

If the sample fails to satisfy the above requirements, an additional two samples may be taken and tested for 14 d in 400°C steam at 10.3 ± 0.7 MPa. After this exposure, the samples shall show a uniform, black, lustrous oxide with no white oxide and have a weight gain of no more than 38 mg/dm^2. If either of these samples fails to satisfy the requirements, the tubes shall be rejected and all other tubes derived from the same ingot as the failed tube shall be individually corrosion-tested to meet the requirements stated above.

5.7 Quality Requirements

5.7.1 General

The contractor shall meet the quality Standards specified in the contractual documents.

5.7.2 Cleanliness

The tubes shall be supplied free of all grease, oil, scale, grit, oxide, moisture, and other foreign materials. Cleaning procedures and tests for determining cleanliness shall be subject to the acceptance of the purchaser. Cleaning materials shall have a maximum of 250 ppm halogens and 1% by weight of sulphur and shall be so certified.

5.7.3 Surface Quality

The internal and external surfaces of the finished tubes shall be examined for defects to the requirements of the Standard V-2 of CSA Standard N285.6.6. The acceptance criteria for the surfaces shall be as detailed in V-2 of CSA Standard N285.6.6.

5.7.4 Soundness

The tubes shall be free of internal defects having indications with a major dimension greater than 1.5 mm.

5.7.5 Dimensional Inspection

The contractor shall perform dimensional inspection to the extent required to ensure compliance with the requirements of the drawing. Inspection procedures shall be supplied to, and accepted by, the purchaser.

6. Inspection, Tests, and Reports

6.1 General

The contractor shall be responsible for, shall provide for, and shall perform all of the inspection and testing specified herein. The inspection and testing shall be conducted in a manner satisfactory to, and shall be subject to acceptance by, the purchaser.

Inspection by the purchaser or his authorized representative shall not in any way relieve the contractor of the inspection duties called for herein. A limited number of spot checks by the purchaser shall be considered part of normal inspection procedures and within the scope of the contract without extra charge. The contractor shall provide all reasonable tooling necessary for the purchaser's representative to conduct spot checks, and shall give assistance as required.

The purchaser shall have the right to specify additional inspection or testing as deemed necessary, with the additional cost of such inspection or testing borne by the purchaser. The contractor shall maintain records of all inspection and tests which shall be made freely available to the purchaser or his authorized representative.

6.2 Chemical Analysis

A sample for chemical analysis shall be taken from one of every five finished tubes of the same diameter and wall thickness derived from the same ingot. The samples shall be analyzed for nitrogen and hydrogen and the results shall conform to the requirements of Clause 5.4 of this Standard.

6.3 Tensile Testing

One sample for testing in the longitudinal direction shall be taken from one of every five tubes. The sample for the test shall be a full-size tubular section, approximately 100 mm long.

The tests shall be performed in accordance with ASTM Standard E8. The strain rate shall be 0.005 ± 0.002 mm/mm/min to 0.2% yield stress. After the 0.2% yield stress has been exceeded, the cross-head speed may be increased to approximately 1.2 mm/min to failure. The results shall be as stated in Clause 5.5 of this Standard.

6.4 Corrosion Testing

One sample at least 50 mm long shall be taken from one finished tube of every five tubes. Samples shall be representative of all sizes, thicknesses, and types of manufacture of tubes supplied in this size range.

The sample shall be degreased, pickled, cleaned, and corrosion-tested in steam at 400°C and at a pressure of 10.3 MPa for 72 h according to the requirements of ASTM Standard G-2.

6.5 Tube Inspection

The manufacturer shall verify by an approved inspection procedure that the tubes meet the requirements of Clause 5.7.

6.6 Dimensions and Cleanliness

The tubes shall be inspected by the contractor to verify that the dimensions, surface finish, and cleanliness are in accordance with the requirements of this Standard and the drawings. A complete dimensional inspection record shall be made on one or more inspection forms for each tube. The inspection forms shall be subject to approval by the purchaser.

6.7 Nondestructive Examination

The ingot shall be inspected and accepted to the criteria of Standard U/T-2 of CSA Standard CAN/CSA-N285.6.6.

6.8 Hydrostatic Testing

The tube shall be tested at the completion of fabrication in accordance with Clause 5.3. The tube shall be isolated from the pressurizing equipment during the time at the specified pressure and a record of pressure against time produced for each test. Minor dressing to remove handling marks may be carried out after testing.

7. Quality Control Records

7.1 Contents of File

The contractor shall maintain a complete file of records for all ingots and accepted tubes, manufacturing, inspection, examination and test data taken before, during, and after manufacture, including the procedures, specifications, and drawings used-all fully identified by pertinent identification numbers. The records shall include all closely related data such as qualifications and approval of procedures and equipment, data on required items, and records of deviations, concession requests, and approvals.

Among other records, the contractor shall maintain an inspection, examination, and test checklist for each tube.

7.2 Maintenance of and Access to Records

Records specified in Clause 7.1 shall be filed and maintained in a manner that will allow access by the purchaser or authorized representatives to specific information contained therein at any time during manufacture. The contractor shall take such steps as may be required to provide suitable protection of all records from deterioration or damage.

8. Packaging and Shipment

8.1

The tubes shall be sealed in polyethylene sleeves and protected by suitable packaging to prevent damage, corrosion, and entry of all foreign material. Suitable means shall be provided for mechanical handling of individual tubes outside the shipping crate.

Packaging and shipping procedures must be submitted to, and accepted by, the purchaser.

National Standard of Canada CAN/CSA-N285.6.3-88

Annealed, Seamless Zirconium Alloy Tubing for Liquid Injection Shutdown System Nozzles

Prepared by
Canadian Standards Association

Approved by
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CAN/CSA-N285.6.3-88
Annealed, Seamless Zirconium Alloy Tubing for Liquid Injection Shutdown System Nozzles

1. Scope

1.1

This Standard establishes the requirements for seamless zirconium alloy tubing of nonuniform wall suitable for incorporation into injection nozzles located in moderator water in the core of a CANDU reactor.

2. Definitions

2.1

The following definitions apply in this Standard:

The front end of a tube—that end of the tube which emerges first from the extrusion die.

The back end of a tube—that end which emerges last from the die.

3. Material

3.1 Ingot Requirements

3.1.1 Ingot Preparation

Zirconium sponge of reactor grade and, if desired, identified reactor-grade scrap of compatible material and the necessary alloying ingredients shall be formed into suitable electrodes. All welding used in the production of electrodes shall be by the electron beam or another process that does not involve risk of contamination by electrode or shield materials. Master alloy additions shall be in a form that does not inhibit solution in the melt.

Melting shall be in a consumable-electrode, vacuum-arc melting furnace. The first melt ingots shall be remelted under similar conditions to form the ingot. Melting practice shall be such as to ensure adequate homogeneity of the ingot and the absence of defects, compounds, and segregation detrimental to subsequent fabrication or serviceability.

3.1.2 Ingot Conditioning

The ingot shall be conditioned by turning or grinding, or both, to remove surface defects, and to disclose and remove undue segregation and porosity.

3.1.3 Ingot Identification

Each ingot shall be metal-die-stamped on the top with the manufacturer's ingot number.

3.1.4 Ingot Chemical Analysis

3.1.4.1 Sampling of Ingot

The ingot shall be sampled at least once for every 800 to 1000 kg of ingot weight. These samples shall be taken uniformly along the length of the ingot so as to sample the top, bottom, and points in between. Additional samples shall be taken in areas where segregation is suspected.

The analysis shall comply with the requirements stated in Clause 3.1.4.2. The procedures for the analysis shall be submitted to and accepted by, the purchaser before analysis is made. The results of each analysis shall be reported for each element specified.

3.1.4.2 Chemical Composition

The requirements for chemical composition shall be as given in Table 3.1, and in accordance with the requirements of Tables 3.2 and 3.3.

3.1.5 Ingot Hardness

The hardness of the ingot shall be determined as described in ASTM Standard E10, at the positions where samples are taken for chemical analysis. The hardness shall not exceed 187 BHN for either alloy R60802 or alloy R60804.

3.1.6 Ingot NDE

The ingot shall be ultrasonically examined to, and meet the requirements of, Standard U/T-2 of CSA Standard CAN/CSA-N285.6.6. Procedures describing such examinations shall be submitted to, and accepted by, the purchaser prior to examination.

Table 3.1
Chemical Composition of Zirconium Alloys

Elements alloyed to zirconium	Alloy R60802	Alloy R60804
Tin	1.20–1.70 wt%	1.20–1.70 wt%
Iron	0.07–0.20 wt%	0.18–0.24 wt%
Chromium	0.05–0.15 wt%	0.07–0.13 wt%
Nickel	0.03–0.08 wt%	—
Niobium	—	—
Carbon	80– 400 ppm	80– 400 ppm
Oxygen	900–1400 ppm	900–1400 ppm
Total Fe + Cr + Ni	0.18–0.38 wt%	0.28–0.37 wt%

Table 3.2
Permitted Impurities for Zirconium Alloys

Permitted impurities	Alloy R60802 ppm, max.	Alloy R60804 ppm, max.
Aluminum	75	75
Boron	0.5	0.5
Cadmium	0.5	0.5
Carbon	—	—
Chromium	—	—
Cobalt	20	20
Copper	50	50
Hafnium	50	50
Hydrogen	20	20
Iron	—	—
Lead	130	130
Magnesium	20	20
Manganese	50	50
Molybdenum	50	50
Nickel	—	70
Niobium	100	100
Nitrogen	65	65
Silicon	120	120
Tantalum	200	200
Tin	—	—
Titanium	50	50
Tungsten	100	100
Uranium	3.5	3.5
Vanadium	50	50

Table 3.3
Permissible Variation in Product Analysis

Element	Permissible variations from specified range, %, or maximum
Tin	0.050
Iron	0.020
Chromium	0.010
Chromium and iron and nickel	0.020
Niobium	0.050
Oxygen	0.007
All others	0.002 or 20%, whichever is smaller

4. Intermediate Product Requirements

4.1 Billet NDE

The billet shall be examined to, and meet the requirements of, Standard U/T-3 of CSA Standard CAN/CSA-N285.6.6.

5. Product Requirements

5.1 Condition of Product

The tubes shall be produced by hot-extrusion and cold-working and shall be supplied in the annealed condition. A nonuniform wall may be produced by the extrusion operation or by machining. Billets for extrusions may be either bored or hot-pierced. Workmanship shall be in accordance with the best practice.

The contractor shall submit a procedure outlining the principal steps in the fabrication of the tubes and the sequence of operations.

5.2 Identification

Each tube shall have an identification stamped upon the back end, outside the final trim line, with the contractor's identification, which shall include a serial number. Records shall be kept that identify the tube with the original ingot from which it was produced and with the processing history of the tube.

5.3 Chemical Composition

The ingot analysis shall be accepted as the chemical composition of the finished tubing except for the elements nitrogen, hydrogen, and oxygen. The analyses for nitrogen, hydrogen, and oxygen shall be determined in accordance with Clause 6.2 and shall comply with the composition requirements of Clause 3.1.4.2.

5.4 Annealing

The finished tubes shall receive a vacuum anneal at a temperature between 600°C and 750°C at an equilibrium absolute pressure not exceeding 0.15 Pa.

5.5 Grain Size

The average grain size of the annealed tube shall not exceed ASTM micrograin size No. 7 when determined in accordance with ASTM Standard E112.

5.6 Mechanical Properties

The material in each of the finished tubes shall have the following minimum properties when tested at room temperature as stated in Clause 6.3:

Ultimate tensile strength	415 MPa
0.2% yield strength	240 MPa
Elongation	20%

5.7 Corrosion Resistance

A sample of each tube shall be corrosion-tested to a procedure meeting the requirements of Clause 6.6.

After exposure the coupons shall show a uniform, black, lustrous oxide film and have a weight gain of no more than 22 mg/dm^2.

If the coupon fails to satisfy the above requirements, two additional coupons may be taken and tested for 14 d in 400°C steam at 10.3 ± 0.7 MPa. After this exposure, the coupons shall show a uniform, black, lustrous oxide and shall have a weight gain of no more than 38 mg/dm. If either of

the coupons fails to satisfy the requirements, a retest may be performed with the prior consent of the purchaser. If the retest fails, the tube shall be rejected.

5.8 Quality Requirements

5.8.1 General

The contractor shall meet the quality Standards specified in the contractual documents.

5.8.2 Surface Finish

The surface of the finished tubes shall meet the surface roughness requirements of the drawing. The surfaces shall be inspected to, and meet the requirements of, Clause 3.1 of CSA Standard CAN/CSA-N285.6.6.

5.8.3 Cleanliness

After the final draw and also after final machining, the surface contamination of the inside and outside tube surfaces shall be removed by means acceptable to the purchaser.

All surfaces of the tubes shall be free from dirt, oil, grease, lubricant, and other contaminants.

Cleaning procedures and tests for determining cleanliness shall be subject to the acceptance of the purchaser. Cleaning materials shall have a maximum of 250 ppm halogens and 1% by weight of sulphur and shall be so certified.

5.8.4 Soundness

The tubes shall be free from defects having indications with a major dimension greater than 1.5 mm.

For tubes produced by a process involving a nonuniform wall extrusion, the billets shall be ultrasonically examined prior to extrusion to meet the requirements of Clause 6.3 of CSA Standard CAN/CSA-N285.6.6. The tubes shall be liquid-penetrant inspected to meet the requirements of Clause 5.3 of CSA Standard N285.6.6.

For tubes produced by a process involving a uniform wall extrusion, an ultrasonic examination shall be done on the tube prior to any machining operations. This inspection shall be in lieu of the liquid-penetrant inspection. The inspection shall meet the requirements of Clause 6.1 of CSA Standard CAN/CSA-N285.6.6.

5.9 Dimensions and Tolerances

Dimensions shall be in accordance with the drawing specified in the tendering documents.

6. Inspection, Tests, and Reports

6.1 General

The contractor shall be responsible for, shall provide for, and shall perform all of the inspection and testing specified herein. The inspection and testing shall be conducted in a manner satisfactory to, and shall be subject to acceptance by, the purchaser.

Inspection by the purchaser or his authorized representative shall not in any way relieve the contractor of the inspection duties called for herein. Spot checks by the purchaser shall be considered part of normal inspection procedures and within the scope of the tender without extra charge. The contractor shall provide all reasonable tooling necessary to conduct spot checks, and shall give assistance as required.

The purchaser shall have the right to specify additional inspection or testing as deemed necessary, with the additional cost of such inspection or testing borne by the purchaser. The contractor shall maintain records of all inspection and tests, which shall be made freely available to the purchaser or his authorized representative.

6.2 Chemical Analysis

A sample for chemical analysis shall be taken from the tube end representative of the top of each ingot and from the tube end representative of the bottom of each ingot. The samples shall be analyzed for nitrogen, oxygen, and hydrogen.

6.3 Tensile Test

A test piece representative of the longitudinal direction shall be taken from the front end of each tube after the final anneal, and shall be machined to the requirements of Figure 7 of ASTM Standard E8. An acceptable alternative test specimen is shown as Figure 3.1 of this Standard.

All tensile tests shall be carried out in accordance with ASTM Standard E8. The strain rate during application of the load up to the 0.2% yield stress shall be 0.005 ± 0.002 mm/mm/min. After the 0.2% yield stress has been exceeded the cross-head speed may be increased to 1.2 mm/min to failure.

The results of the tensile test shall satisfy the requirements of Clause 5.6 of this Standard.

Should the first test piece not satisfy the requirements of Clause 5.6, two further test pieces may be taken from the same end of the tube and tested in an identical manner. If the average of the three results

satisfies the requirements of Clause 5.6, the tube is acceptable. If the average does not satisfy the requirements, the tube shall be rejected.

6.4 Hydrostatic Pressure Test

Each tube shall be hydrostatically pressurized at 20°C for a minimum of 30 s, at a pressure that will impose a fibre stress of at least 70 MPa on the uniform section of the tube wall as determined by the following formula:

$$P = \frac{2st}{D}$$

where
P = pressure, MPa
s = fibre stress, MPa
t = minimum specified wall thickness, m
D = specified maximum continuous outside diameter, m

The tube shall be isolated from the pressurizing equipment during the time at the specified pressure. The tube shall exhibit no leakage during the test and the pressure drop during the period at maximum pressure shall not exceed 1.0 MPa. The tube shall be visually examined after testing for evidence of distortion caused by the pressure.

6.5 Nondestructive Examinations

All ingots, intermediate products, and tubes manufactured to this Standard shall receive nondestructive examination as detailed in the previous sections.

6.6 Corrosion Test

One coupon measuring approximately 12.5×100 mm shall be taken from the front end of each finished tube after the final anneal and immediately prior to final machining. The coupon shall be degreased, pickled, cleaned, and corrosion-tested according to the requirements of ASTM Standard G2. The sample shall be exposed to steam at 400°C and at a pressure of 10.3 MPa for 72 h.

6.7 Dimensional Inspection

6.7.1

The contractor shall perform dimensional inspection to the extent required to ensure compliance with the requirements of the drawing. Inspection procedures shall be supplied to, and approved by, the purchaser.

6.7.2

Wall thickness shall be measured by a means acceptable to the purchaser. An acceptable method would be a continuous helical scan with a pitch of 20 mm using ultrasonic measurement instruments. The measurement method shall provide accuracy to within 0.025 mm, and the reference temperature for all dimensional measurements shall be 20°C. Wall thickness shall be measured at sections 3 inches from each end of the tube at eight positions of 45° spacing.

6.8 Inspection, Examination, or Test Failure

In the event of the failure of any ingot, tube, or test piece to meet an inspection or test requirement specified herein, the contractor shall notify the purchaser and shall obtain authorization before repair work is undertaken on material intended to be presented to the purchaser as meeting the requirements of this Standard.

If repair is likely to affect the results of tests or work previously completed, appropriate reinspection and retesting shall be carried out.

The procedures to ensure a satisfactory repair shall be subject to acceptance by the purchaser.

7. Quality Control Records

7.1 Contents of File

The contractor shall maintain a complete file of records for all accepted tubes and ingots; manufacturing, inspection, examination, and test data taken before, during, and after manufacture, including the procedures, specifications, and drawings used-all fully identified by pertinent identification numbers. The records shall include all closely related data such as qualifications and approval of procedures and equipment, data on required items and records of deviations, concession requests and approvals.

Among other records, the contractor shall maintain an inspection, examination, and test checklist for each tube.

7.2 Maintenance of and Access to Records

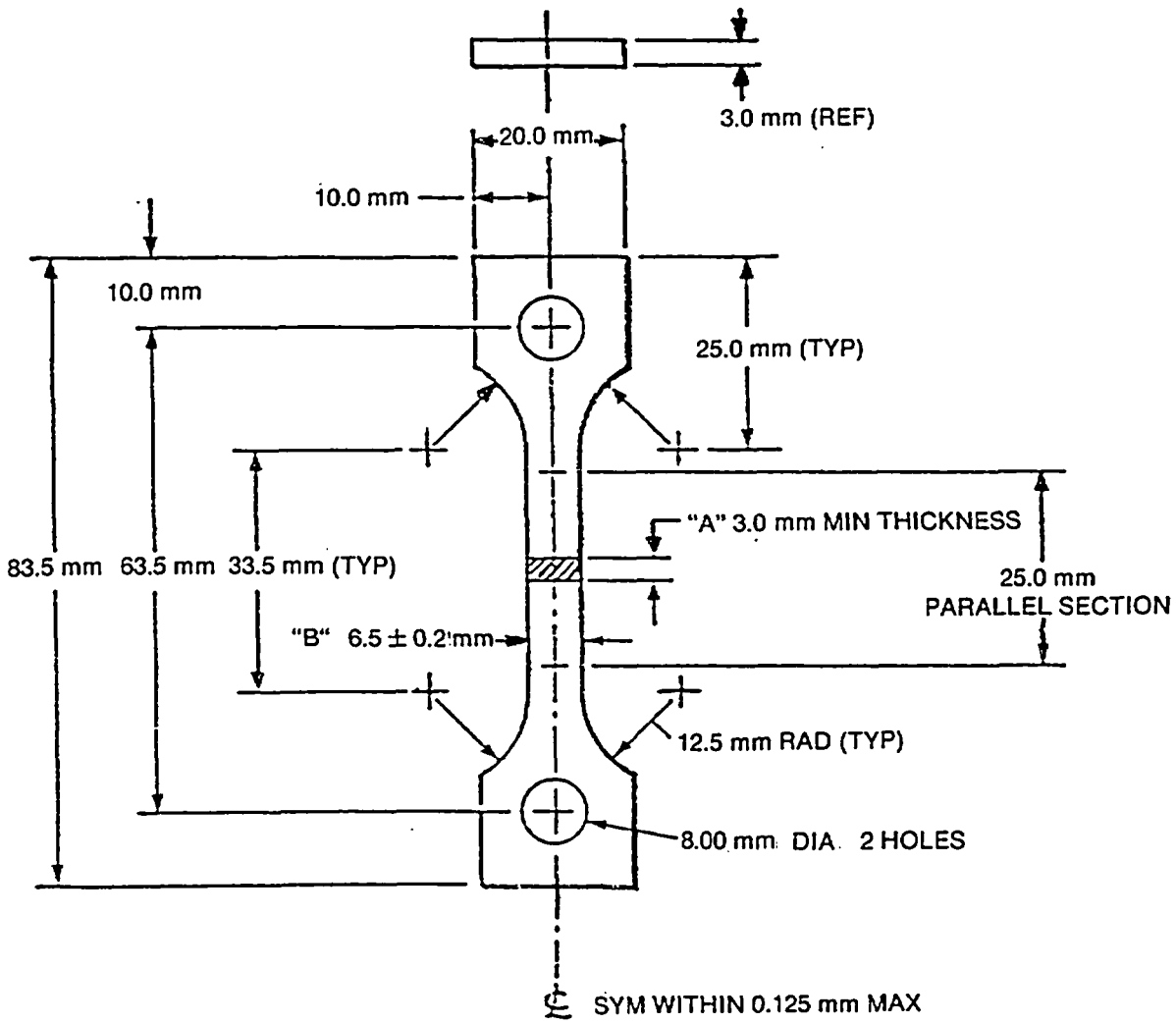
Records specified in Clause 7.1 shall be filed and maintained in a manner that will allow access by the purchaser or authorized representatives to specific information contained therein at any time during manufacture. The contractor shall take such steps as may be required to provide suitable protection of all records from deterioration or damage.

8. Packaging and Shipment

8.1

The tubes shall be sealed in a polyethylene sleeve and protected by suitable packaging to prevent damage, corrosion, and entry of all foreign material. Suitable means shall be provided for mechanical handling of individual tubes, outside the shipping crate.

Packaging and shipping procedures shall be submitted to, and accepted by, the purchaser.



Notes:

(1) *Specimen shall be suitable for use in a* 25 mm *extensometer.*
(2) *Gauge length for elongation to failure shall be* L = 4.5 (cross-sectional area)$^{1/2}$
(3) *Dimensions "A" and "B" shall be constant* ± 0.025 mm *over parallel section.*
(4) *Identification marks shall be in the gripper area and not in the parallel section.*
(5) *Dimensional Tolerances: one place of decimals* ± 0.25 mm; *two places of decimals* ± 0.125 mm.
(6) *Dimensions "A" and "B" shall be recorded to the nearest* 0.0025 mm. *The cross-sectional area is to be rounded to the next higher* 0.0025 mm^2.

Figure 3.1
Tensile Test Specimen

National Standard of Canada CAN/CSA-N285.6.4-88

Thin-Walled, Large-Diameter Zirconium Alloy Tubing

Prepared by
Canadian Standards Association

Approved by
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CAN/CSA-N285.6.4-88
Thin-Walled, Large-Diameter Zirconium Alloy Tubing

1. Scope

1.1

This Standard establishes the requirements for the fabrication and properties of thin-walled zirconium alloy tubing used as calandria tubes and as guide tubes for reactivity control rods in a CANDU reactor. Generally, this specification applies to tubing with a diameter to wall thickness ratio greater than 80:1.

2. Definitions

2.1

The following definitions apply in this Standard:

Ovality—the difference between maximum and minimum outside diameters measured in any one cross-section, exclusive of weld beads or other accepted local irregularities.

Out of straightness—the maximum gap between the surface of the tube and a straight edge held in the horizontal plane through the axis of the tube and touching it in two or more places when the tube is supported at its ends. The length of the straight edge is defined by the requirement.

Radial bow—the maximum radial deviation of the actual tube centreline from an imaginary axis (datum axis) joining the centres of the ends (or specified reference planes) of the tube (generally determined as half of the TIR measurement).

Total indicated runout (TIR.)—the maximum runout of the outside surface of the tube measured at one point along the length when a tube is rotated through 360° about its axis, exclusive of weld bead or other acceptable local irregularities.

3. Material

3.1 Ingot Requirements

3.1.1 Ingot Preparation

Zirconium sponge of reactor grade and, if desired, identified reactor-grade scrap of compatible material and the necessary alloying ingredients shall be formed into suitable electrodes. All welding used in the production of electrodes shall be by the electron beam or another process that does not involve risk of contamination by electrode or shield materials. Master alloy additions shall be in a form that does not inhibit solution in the melt.

Melting shall be in a consumable-electrode, vacuum-arc melting furnace. The first melt electrodes so produced shall be remelted under similar conditions to form the ingot. The ingot may again be remelted at the discretion of the contractor, but such additional remelting and the reason for it shall be reported. Melting practice shall be such as to ensure adequate homogeneity of the ingot and the absence of defects, compounds, and segregation detrimental to subsequent fabrication or serviceability.

3.1.2 Ingot Conditioning

The ingot shall be conditioned by turning or grinding, or both, to remove surface defects, and to disclose and remove segregation and porosity.

3.1.3 Ingot Identification

Each ingot shall be metal-die-stamped on the top with the manufacturer's ingot number.

3.1.4 Ingot Chemical Analysis

3.1.4.1 Sampling of Ingot

The ingot shall be sampled at least once for every 800 to 1000 kg of ingot weight. These samples shall be taken uniformly along the length of the ingot so as to sample the top, bottom, and points in between. Additional samples shall be taken in areas where segregation is suspected.

The analysis shall comply with the requirements stated in Clause 3.1.4.2. The procedures for the analysis shall be submitted to, and accepted by, the purchaser before analysis is made. The results of each analysis shall be reported for each element specified.

3.1.4.2 Chemical Composition

The requirements for chemical composition shall be as given in Table 4.1 and in accordance with the requirements of Tables 4.2 and 4.3.

Table 4.1
Chemical Composition of Zirconium Alloys

Elements alloyed to zirconium	Alloy R60802	Alloy R60804
Tin	1.20–1.70 wt%	1.20–1.70 wt%
Iron	0.07–0.20 wt%	0.18–0.24 wt%
Chromium	0.05–0.15 wt%	0.07–0.13 wt%
Nickel	0.03–0.08 wt%	—
Niobium	—	—
Carbon	80– 400 ppm	80– 400 ppm
Oxygen	900–1600 ppm	900–1600 ppm
Total Fe + Cr + Ni	0.18–0.38 wt%	0.28–0.37 wt%

Table 4.2
Permitted Impurities for Zirconium Alloys

Permitted impurities	Alloy R60802 ppm, max.	Alloy R60804 ppm, max.
Aluminum	75	75
Boron	0.5	0.5
Cadmium	0.5	0.5
Carbon	—	—
Chromium	—	—
Cobalt	20	20
Copper	50	50
Hafnium	50	50
Hydrogen	25	25
Iron	—	—
Lead	130	130
Magnesium	20	20
Manganese	50	50
Molybdenum	50	50
Nickel	—	70
Niobium	50	50
Nitrogen	65	65
Silicon	120	120
Tantalum	200	200
Tin	—	—
Titanium	50	50
Tungsten	100	100
Uranium	3.5	3.5
Vanadium	50	50

Table 4.3
Permissible Variation in Product Analysis

Element	Permissible variations from specified range, %, or maximum
Tin	0.050
Iron	0.020
Chromium	0.010
Chromium and iron and nickel	0.020
Niobium	0.050
Oxygen	0.007
All others	0.002 or 20%, whichever is smaller

3.1.5 Ingot Hardness

The hardness shall be determined as described in ASTM Standard E10, at the positions where samples are taken for chemical analysis. The hardness shall not exceed 200 BHN for either alloy R60802 or alloy R60804.

3.1.6 Ingot NDE

The ingot shall be ultrasonically examined to, and meet the requirements of, Clause 6.2 of CSA Standard CAN/CSA-N285.6.6. Procedures describing such examinations shall be submitted to and accepted by the purchaser prior to examination.

3.2 Strip

3.2.1 General

The ingot shall be fabricated into a strip that meets the specified dimensions and properties.

3.2.2 Examination

The strip shall be free of defects as shown by an inspection technique and criteria as agreed between the strip manufacturer and the purchaser.

3.2.3 Tensile Strength

The tensile properties specified for the strip shall be those required to produce tubes that meet the tensile properties specified in Clause 5.3.2.

3.2.4 Corrosion Resistance

A strip sample from each lot shall meet the corrosion-resistance requirement as detailed in Clause 5.3.3. A lot shall be defined as material derived from one ingot hot- and cold-reduced by the same route at the same time and heat-treated at the same time.

4. Process Requirements

4.1 Manufacturing

The following requirements shall govern the manufacture of the thin-walled tubes.

4.1.1 General

The finished product shall be in the form of tubes that are seam-welded and sized. Depending on the end use, a stress relief may be required after sizing.

Only accepted procedures shall be used for the fabrication of the tubes.

4.1.2 Seam Welds

Welding of the tubes or strip shall be performed by an automatic or semiautomatic process. Atmospheric control during welding shall be such that neither weld nor parent metal is contaminated by impurities. The seam shall consist of one continuous run of weld. Where filler metal is used, it shall be the same as the parent metal (Clause 3.1.4.2), or its chemical composition shall comply with the requirements of ASTM Standard B351, Grade R60802 or Grade R60804, with the following exceptions: oxygen 1600 ppm maximum and vanadium 50 ppm maximum.

Repairs are allowed, including refusion passes, provided that they have been duly qualified as part of the weld qualification tests and are acceptable to the purchaser. Fusion repair of parent-metal defects is also permitted providing the repair has been qualified.

4.1.3 Seam Levelling

Where seam levelling is mandatory, it shall be done by rolling to ensure that the weld bead does not protrude beyond the dimensional tolerances specified on the drawing.

4.1.4 Annealing

After welding and, if required, seam-levelling, all tubes shall be annealed in such a manner as to produce a product and microstructure in accordance with this Standard. An acceptable process involves annealing at 730°C to 760°C for 0.5 h, with not more than 2 h total above 650°C, which shall be carried out in a vacuum at an equilibrium absolute pressure not exceeding 0.15 Pa. Important parameters of the annealing process shall be established as part of the qualification tests.

Prior to annealing, the tubes shall be cleaned in such a manner as to ensure freedom from contamination that might affect resistance to corrosion or other specified requirements.

4.1.5 Residual Stress

Residual stresses in the finished tubes shall be moderate in intensity and uniform throughout the tube, both circumferentially and longitudinally. This is to ensure that the tubes remain stable during storage and transportation between manufacture and installation in the calandria, and also during service from stress relief under irradiation. Depending on the procedure, type of tube production, or service requirements, tubes may or may not require multiple stress-relieving to achieve this aim.

The amount of straightening or working operations after the final heat treatment will affect residual stress patterns. Compliance with Clause 4.2 is intended to satisfy this concern.

4.2 Qualification of Manufacturing Processes

4.2.1 General

Process qualification tests are required for each manufacturing process. Processes shall be qualified for each of the significant variables. The process qualification tests shall culminate in the contractor producing a number of qualification tubes to meet the full requirements of this Standard and applicable sections of the tendering document. Qualification shall culminate in the submission of a qualification report to the purchaser for acceptance.

Subsequent revisions to manufacturing processes and quality procedures which affect acceptability of the product may require requalification at the discretion of the purchaser.

4.2.2 Weld Procedure Qualification

All welds, welding operators and welding procedures used in the fabrication of tubes to this specification shall be qualified in accordance with the requirements of the ASME Code, Sections III and IX and this Standard. Representative weld specimens for the tube seam weld shall be supplied to the purchaser's representative for acceptance prior to production, or when process changes are made. Only qualified procedures shall be used.

4.2.3 Metallographic Tests

When establishing weld procedures prior to production welding, and following any change in the accepted procedure, the material of the weld and heat-affected zone, after annealing, shall meet the requirements of Clause 6.3 of this Standard.

4.2.4 Qualification for Residual Stress

4.2.4.1 General

The complete fabrication procedure used shall be qualified for stability of the tubes and acceptance criteria established by performing dimensional surveys on sample tubes before and after thermal stress relief. The procedure for qualifying a process for residual stress is detailed below in Clauses 4.2.4.2 and 4.2.4.3. The number of tubes requiring such qualification shall be as detailed on the tendering documents.

Prior to any stress-relieving the tubes shall be cleaned to ensure freedom from contamination that may affect corrosion resistance or other properties.

4.2.4.2 Thermal Treatment Qualification

For each type to be qualified, the required number of tubes shall be dimensionally surveyed on completion of the proposed fabrication route, excluding the end flaring operation. The tubes shall be given a single vacuum stress-relief treatment at 500 ± 15°C for 1 h ± 5 min at an equilibrium pressure not exceeding 0.15 Pa while suspended vertically, and cooled in vacuum to a temperature less than 260°C. Cooling to 175°C shall be either in vacuum or in inert atmosphere. The qualification tubes shall be once more surveyed and all shall be within the drawing tolerances as stated in the applicable drawing.

Should any qualification sample fail to meet tolerances, the process shall be suitably modified and the attempt repeated in total for that type.

The dimensional survey data shall always be taken at the same lengthwise positions on each tube and the maximum bow positions referenced peripherally to the longitudinal weld.

4.2.4.3 Storage and Transportation Qualification

When required by the contract, the condition of manufactured tubes shall be qualified by simulated storage and transportation exposure to verify that the tubes will have dimensions within the manufacturing tolerances at the time of installation.

An example of a procedure agreed to between the purchaser and the manufacturer involves dimensionally surveying a required number of tubes for bow, then boxing the tubes in a manner that determines any effect of the seam-weld orientation. The tubes are then transported by truck a minimum of 400 km and then unpacked and the dimensions surveyed. The tubes are surveyed again after repacking and storage at different temperatures for up to 30 d. On completion of the test the tubes shall meet the dimensional requirements specified on the drawings.

5. Product Requirements

5.1 Quality of Finished Tubes

5.1.1 General

The contractor shall meet the requirements of the quality Standards specified in the contractural documents.

5.1.2 Surface Quality

Surfaces of the finished tubes, excluding expanded ends, shall be visually examined for internal and external defects. Both surfaces shall meet the requirements of Clause 3.2 of CSA Standard CAN/CSA-N285.6.6.

Surface irregularities that have different combinations of depth, width, and other dimensions from those defined in Clause 3.2 of CSA Standard CAN/CSA-N285.6.6, and are considered by the purchaser to meet the intent of this Clause, shall be deemed acceptable.

5.1.3 Surface Cleanliness

All grease, oil, scale, grit, oxide, nitride, weld spatter, dirt, liquid penetrant, and other foreign material shall be completely removed from internal and external surfaces.

Cleaning procedures to remove contamination and tests for determining cleanliness shall be subject to the approval of the purchaser. Cleaning materials shall have a maximum of 250 ppm halogen and 1% by weight of sulphur and shall be so certified. Final cleaning materials shall contain a maximum of 100 ppm halogen. Pickling procedures shall also be submitted to the purchaser as required in Clause 4.2.

All components shall be thoroughly cleaned before any heating operation.

5.1.4 Soundness

The tubes shall be nondestructively examined to the requirements stated in Clauses 6.4, 6.5, and 6.6.

5.2 Hydrostatic Test

When required by the contractual documents, each tube shall withstand the specified hydrostatic test pressure for a minimum of 10 min.

5.3 Product Material Requirements

5.3.1 Chemical Composition

The ingot supplier's analysis shall be accepted as the chemical composition of the tube except for hydrogen and nitrogen content, which shall be determined from the finished tube (see Clause 6.8) and shall be as follows:

Hydrogen	25 ppm (max.)
Nitrogen	80 ppm (max.)

5.3.2 Mechanical Properties

5.3.2.1

The mechanical properties of the material in the finished tubes shall not be less than the room-temperature mechanical properties specified in Clauses 5.3.2.2 and 5.3.2.3 when tested in accordance with Clause 6.9 of this Standard.

5.3.2.2

For calandria tubes

(a) the longitudinal tensile strength shall be as follows:

(i) Ultimate tensile strength: 425 MPa (min.);
(ii) Yield strength (0.2% offset): 320 MPa (min.);
(iii) Elongation in 50 mm: 20% (min.).

(b) the transverse tensile strength shall be as follows:

(i) Ultimate tensile strength: 415 MPa (min.);
(ii) Yield strength (0.2% offset): 320 MPa (min.);
(iii) Elongation in 50 mm: 20% (min.).

5.3.2.3

For reactivity mechanism guide tubes the transverse tensile strength shall be as follows:

(a) Ultimate tensile strength: 415 MPa (min.);
(b) Yield strength (0.2% offset): 300 MPa (min.);
(c) Elongation in 50 mm 20% (min.).

5.3.3 Corrosion Resistance

Material in the finished tubes shall be sampled and corrosion-tested to a procedure meeting the requirements of Clause 6.7.

After exposure, the specimens shall show a uniform, black, lustrous oxide film and have a weight gain of no more than 22 mg/dm^2. The weld seam shall not show any spot, line, or area of white oxide.

If the sample fails to satisfy the above requirements, two additional samples may be taken and tested for 14 d in 400°C steam at 10.3 ± 0.7 MPa. After this exposure, the samples shall show a uniform, black, lustrous oxide with no white oxide and have a weight gain of no more than 38 mg/dm^2. If any of these samples fails to satisfy the requirements, the contractor shall corrosion-test every tube made from the same ingot as the failed tube. All tubes failing to satisfy both of the above tests shall be rejected.

5.3.4 Tube Weight

Each tube shall be weighed on calibrated scales accurate to ±0.1 kg. The weight shall be recorded to the nearest 0.1 kg.

6. Inspection, Tests, and Reports

6.1 General

The contractor shall be responsible for all testing, and inspection services and facilities except where otherwise specified.

The inspection and testing shall be conducted in a manner satisfactory to the purchaser. Surveillance by the purchaser or his quality surveyor shall not in any way relieve the contractor of the inspection duties specified herein.

The purchaser has the right to specify additional inspection or testing, with the additional cost of such testing borne by the purchaser.

6.2 Inspection and Test Requirements for Nonconforming Tubes

In the event any tube fails to meet inspection or test requirements specified herein, the contractor shall notify the purchaser and obtain authorization before repair is undertaken on material intended to be presented to the purchaser as meeting the requirement of this Standard, unless such repair is part of a previously qualified procedure.

If the repairs are likely to affect the results of tests or work previously completed, appropriate reinspection and retesting shall be carried out. The quality control procedures to be followed to ensure a satisfactory repair shall be submitted to the purchaser (Clause 4.1.1).

The above shall not apply in cases where rework by accepted procedure results in tubes compliant with the specified requirements.

6.3 Metallographic Examination

A sample from a finished tube (prior to end expansion in calandria tubes) shall be examined to determine the grain structure. The complete weld, heat-affected zone, and parent material shall be included in the sample. A photomicrograph shall be taken of the above sample. The grain structure of the sample shall be similar to that shown by an applicable illustration supplied by the purchaser.

6.4 Radiographic Examination

All tubes shall have the entire length of the seam weld radiographed to the requirements of Standard R-1 of CSA Standard CAN/CSA-N285.6.6.

6.5 Liquid-Penetrant Examination

All finished tubes shall have the welds liquid-penetrant-inspected. The length of the outer surface of the weld and the inner surface, as far as is practical, shall be inspected. The examination shall be to the requirements of Standard LP-1 of CSA Standard CAN/CSA-N285.6.6.

6.6 Ultrasonic Examination

Prior to end-flaring, calandria tubes shall be ultrasonically examined for surface and volumetric defects in accordance with the requirements of Standard U/T-6 of CSA Standard CAN/CSA-N285.6.6.

An ultrasonic standard containing the reference notches shall be supplied by the purchaser. The supplier shall demonstrate to the purchaser that the procedure provides adequate discrimination and repeatability by the ability of the system to reliably detect the reference notches of the ultrasonic standard.

6.7 Corrosion Test

Samples at least 25 × 50 mm shall be taken from finished tubes representative of material from the uppermost and lowermost portions utilized from each ingot.

The longer dimensions of the sample shall include the weld seam and the heat-affected zone on either side of it. The sample shall be degreased, pickled, cleaned, and corrosion-tested in accordance with the requirements of ASTM Standard G2. The samples shall be exposed to steam at 400°C and a pressure of 10.3 MPa for 72 h.

6.8 Chemical Analysis

Ingot analyses showing the elements listed in Clause 3.1.4.2 of this Standard shall be submitted to the purchaser. These analyses shall be accepted by the purchaser as representing the chemical composition of the tubes, except for hydrogen and nitrogen, which shall be determined on samples from finished tubes. These samples shall be taken from tubes representative of material from the uppermost and lowermost portions utilized from each ingot. The results shall conform to the requirements of Clause 5.3.1.

The purchaser reserves the right to reject tubes for which a check analysis shows departure from the requirements of this Standard.

6.9 Tensile Test

One sample for testing in the transverse direction shall be taken from each finished tube.

For tubes manufactured as calandria tubes, samples for testing in the longitudinal direction shall be taken from one out of every ten tubes from each ingot and shall be representative of different tube-annealing batches. These samples may be taken from tubes with unsatisfactory welds or dimensions, provided test samples in the transverse direction are also taken from the same tubes. The materials for the longitudinal and transverse tests shall not include weld material.

The tests shall be performed in accordance with ASTM Standard E8. The strain rate shall be 0.003 to 0.007 mm/mm/min to 0.2% yield strength. After the 0.2% yield strength has been exceeded, the crosshead speed shall be set at approximately 1.2 mm/min to failure.

The test specimen shall be as shown in Figure 13 of ASTM Standard E8. The results shall meet the requirements of Clause 5.3.2 of this Standard.

6.10 Hydrostatic Testing

The tube shall be tested at completion of fabrication in accordance with Clause 5.2. Minor dressing to remove handling marks may be carried out after testing. The tube shall be isolated from the pressurizing equipment during the time at specified pressure, and a record of pressure against time produced for each test.

6.11 Final Inspection and Records

The tubes shall be inspected by the contractor to verify that the dimensions, surface finish, and cleanliness are in accordance with the requirements of this Standard and the purchaser's drawings. Final dimensional inspection shall be made not less than 24 h after completion of manufacture. A complete dimensional inspection record shall be made on one or more inspection forms for each tube. The inspection forms shall be submitted to the purchaser for acceptance.

7. Packaging

7.1

All tubes shall be in sealed polyethylene sleeves and protected by suitable packaging to prevent damage, corrosion, and the entry of foreign materials. Suitable means shall be provided for mechanical handling of individual tubes, outside the shipping crate.

Packaging and shipping procedures must be submitted to, and accepted by, the purchaser.

National Standard of Canada CAN/CSA-N285.6.5-88

Zirconium Alloy Wire for Fuel-Channel Spacers

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CAN/CSA-N285.6.5-88
Zirconium Alloy Wire for Fuel-Channel Spacers

1. Scope

1.1

This Standard establishes the requirements for zirconium alloy wire used to form the spacers between the fuel channels and calandria tubes in a CANDU reactor.

2. Definition

2.1

The following definition applies in this Standard:

Lot—in this Standard, a lot shall consist of all material of the same size, shape, condition, and finish of an order produced from the same ingot and annealed in the same charges throughout each of the heat-treating operations.

3. Manufacturing Requirements

3.1

The production sequence for wire making shall include consumable-electrode, vacuum-arc, multiple-melted ingots as starting material. The ingot shall be forged to billet and then extruded and hot-worked to an approximately 30 mm diameter bar. The bar shall be further reduced by hot-swaging or rocking at no more than 565°C, followed by annealing (700 ± 30°C for 30 min). The rod shall be reduced to wire by suitable cold-working techniques with intermediate annealing and conditioning. The next to final and final anneals (700 ± 30°C for 30 min) shall be in vacuum at an equilibrium absolute pressure not exceeding 0.15 Pa.

4. Ingot Requirements

4.1 Preparation of Ingot

Zirconium sponge of reactor grade and, if desired, identified reactor-grade scrap of compatible material and the necessary alloying ingredients shall be formed into suitable electrodes. All welding used in the production of electrodes shall be by the electron beam or another process that does not involve risk of contamination by electrode or shield materials.

Melting shall be in a consumable-electrode, vacuum-arc melting furnace with a residual inert-gas atmosphere. The first melt electrodes so produced shall be remelted under similar conditions to form the ingot. The ingot may be again remelted at the discretion of the contractor, but such additional remelting and the reason for it shall be reported.

The addition of niobium shall be by means of a zirconium/niobium master alloy having a niobium concentration not exceeding 80% by weight or by the melting of a co-reduced zirconium 2.5% niobium sponge. Any addition shall be carefully controlled to ensure uniform distribution of niobium in the ingot.

4.2 Conditioning of Ingot

The ingots shall be conditioned by turning or grinding, or both, to remove surface defects, segregation, or porosity. Limited removal of defects may be permitted at the discretion of the purchaser.

4.3 Identification of Ingot

Each ingot shall be metal-die-stamped on the top with the manufacturer's ingot number.

4.4 Ingot Sampling and Chemical Composition

4.4.1

The ingot shall be sampled at the top, middle, and bottom. Additional samples shall be taken in areas where segregation is suspected. All samples shall be analyzed.

4.4.2

The chemical composition shall meet the requirements of Table 5.1 and be in accordance with Table 5.2.

4.5 Hardness of Ingot

The hardness shall be determined as described in ASTM Standard E10, at the positions where samples are taken for chemical analysis. The hardness shall not exceed 220 BHN.

Table 5.1
Chemical Composition of Zirconium-Niobium-Copper Alloy

Elements alloyed to zirconium	Zr:2.5 wt% Nb:0.5 wt% Cu
Niobium	2.4–2.8%
Oxygen	800–1200 ppm
Copper	0.3–0.7 wt%

Table 5.2
Permitted Impurities in Zirconium-Niobium-Copper Alloy

Permitted impurities	ppm, max.
Aluminum	75
Boron	0.5
Cadmium	0.5
Carbon	300
Chromium	200
Cobalt	20
Hafnium	100
Hydrogen	25
Iron	1500
Lead	130
Magnesium	20
Manganese	50
Nickel	70
Nitrogen	65
Silicon	120
Tin	50
Titanium	50
Tungsten	100
Uranium	3.5
Vanadium	50

Note: *All other impurities measured shall be reported.*

5. Intermediate Product Requirements

5.1

The hot-worked rod shall be conditioned by removing a minimum of 0.06 mm from the surface to a diameter and finish suitable for ultrasonic inspection. It shall then be examined by the ultrasonic and liquid-penetrant methods outlined in Clauses 7.2.1 and 7.2.2. The rod shall have a hardness not exceeding 92 Rb when tested in accordance with Clause 7.4.1.

6. Product Requirements

6.1 General

The product shall be in the form of annealed wire. The wire shall be in well-formed coils, free from twists, kinks, and surface notches or irregularities detrimental to fabrication or service. Workmanship shall be in accordance with the best practice and such that the wire shall be suitable for making close-coiled springs.

6.2 Quality Requirements

6.2.1 General

The contractor shall meet the requirements of the quality Standards specified in the contractual documents.

6.2.2 Soundness

The wire shall be free from surface defects as determined by liquid-penetrant examination in accordance with the requirements described in Clause 7.2.2, and from internal defects by the fracture examination described in Clause 7.3.2 in accordance with the requirements of the bend test described in Clause 6.4.2.

6.2.3 Cleanliness

The wire shall be supplied free of all grease, oil, scale, grit, oxide, moisture, and other foreign materials. Cleaning procedures and tests to determine cleanliness shall be subject to the acceptance of the purchaser. Cleaning materials shall have a maximum of 250 ppm halogen and 1% by weight of sulphur and shall be so certified.

6.3 Chemical Composition

The ingot supplier's analysis shall be accepted as the chemical analysis of the wire except that hydrogen, nitrogen, oxygen, niobium, and copper shall be determined on the finished product and shall meet the requirements of Clause 4.4.

The purchaser reserves the right to reject wire for which the above analysis or a check analysis shows departure from the requirements of this Standard.

6.4 Mechanical Properties

6.4.1 Hardness

The annealed (700 ± 30°C/30 min) wire shall be tested for hardness in accordance with the requirement of Clause 7.4.1. The hardness shall not exceed 92 R_B.

6.4.2 Bend Tests

The annealed wire shall be tested in bending as described in Clauses 7.3.1 and 7.3.2. The bent wire shall show no cracks when magnified by ten times its size. The fracture surfaces of the samples fractured as described in Clause 7.3.2 shall show no sign of internal defects.

6.4.3 Tensile Tests

Wire tested to the requirements of Clause 7.4.3 shall show the following minimum properties:

Ultimate tensile strength	760 MPa
0.2% yield strength	620 MPa
Elongation in 25 mm	5%

6.5 Corrosion Resistance

The wire shall be corrosion-tested in accordance with a procedure meeting the requirements of Clause 7.4.4.

After exposure, the coupons shall show a uniform, lustrous oxide film and have a weight gain not exceeding 35 mg/dm^2.

If the samples fail to satisfy the above requirements, an additional two samples may be taken from the same lot and tested for 14 d at 400°C steam at 10.3 MPa. After this exposure, the samples shall show a uniform, lustrous finish and shall show a weight gain of no more than 90 mg/dm^2. If any of these fails to satisfy the requirements, the lot shall be rejected.

6.6 Dimensions and Tolerances

The cross-sectional dimensions of the wire shall be measured after final processing and shall be within specified tolerances. When specified, the corner radius shall be measured as described in Clause 7.4.5.

7. Inspection, Tests, and Reports

7.1 General

The contractor shall be responsible for all testing and inspection services and facilities except where otherwise specified. The product shall be carefully examined during and after manufacture to determine its conformance with this specification with respect to material, workmanship, finish, marking, and dimensions. Inspection and testing shall be conducted, in a manner satisfactory to, and shall be subject to acceptance by, the purchaser. Inspection and test reports shall be submitted to the purchaser.

7.2 Nondestructive Examinations

7.2.1 Ultrasonic Inspection of Swaged Rod

Each rod in the condition described in Clause 5 shall be ultrasonically examined in accordance with Clause 6.4 of CSA Standard CAN/CSA-N285.6.6. Acceptance criteria shall be those outlined in Clause 6.4 of CSA Standard CAN/CSA-N285.6.6.

7.2.2 Liquid-Penetrant Examination

The following intermediate and final products shall be liquid-penetrant examined and shall meet the requirements listed below:

(a) the full length of each swaged, centreless ground rod;

(b) 500 mm from each end of each coil of finished wire.

The liquid-penetrant examination shall be in accordance with Standard LP-2 of CSA Standard CAN/CSA-N285.6.6. Acceptance criteria shall be as listed in Clause 5.2 of CSA Standard CAN/CSA-N285.6.6.

7.3 Destructive Examination

7.3.1 Bend Tests

Two samples of annealed wire from each lot (a sample shall be taken from each coil when a lot consists of more than one coil) shall be bent 180° around a diameter of 1.25T, where T is the greater of the wire cross-section sides, and about an axis normal to the T dimension. The wire shall be bent in one direction and then a separate straight portion of the same sample shall be similarly bent in the opposite direction. The bent wire shall be examined while magnified at ten times its size.

7.3.2 Fracture Test

Two random samples from each lot shall be fractured by reverse bending and the fracture surfaces thus produced shall be examined while magnified at ten times its size.

7.4 Wire Properties

7.4.1 Hardness

Two samples of wire from each lot shall be tested for hardness in accordance with the requirements of ASTM Standard E92.

7.4.2 Chemical Analysis

Each lot of wire shall be analyzed for hydrogen, nitrogen, oxygen, niobium, and copper, and shall meet the requirements for these elements as specified in Clause 4.4.

7.4.3 Tensile Test

Two samples of wire, heat-treated as described below to meet a hardness of 260 ± 10 VPN, shall be taken from each lot (samples shall be taken from separate coils when a lot consists of more than one coil). The samples shall be tensile-tested at room temperature according to the requirements of ASTM Standard A370, except that the gauge length may be 25 mm. The strain rate during application of the load to the 0.2% yield stress shall be 0.005 ± 0.002 mm/mm/min. Beyond the 0.2% yield stress the cross-head speed may be increased to approximately 1.2 mm/min. Both samples shall meet the requirements of Clause 6.4.3.

Prior to tensile-testing, the material shall be heat-treated in the following manner. It shall be heated for 15 min in a deoxidized slag-free salt bath at 860 ± 8°C and then quenched in cold water. It shall then be pickled, cleaned, vapour-degreased, and then aged in vacuum at 538 ± 8°C for 7 h at a pressure not exceeding 0.15 Pa.

7.4.4 Corrosion Test

Two samples for each lot, at least 300 mm long, and heat-treated as described in Clause 7.4.3, shall be degreased, pickled to remove 0.025 mm of surface, cleaned, and corrosion-tested according to the requirements of ASTM Standard G2. The pickling bath used shall be that specified in ASTM Standard G2 for zirconium-niobium alloys. The samples shall be exposed to steam at 400°C and at a pressure of 10.3 MPa for 72 h.

7.4.5 Corner-Radius Measurement

A short length of wire from each lot shall be cross-sectioned, mounted, and prepared for metallographic examination. The corners of the wire shall be projected onto a screen at a suitable magnification and the radius of the corner compared with a standard radius at the same magnification. It shall be cause for rejection if the projected radius is outside the range stated in the contractual documents.

7.5 Test Reports

Test reports, heat-treatment records, and inspection reports, including ingot data, each signed by a responsible technical representative of the contractor and covering all tests and analyses, shall be prepared and submitted to the purchaser. When inspection or testing is subcontracted to an outside agency, the reports shall be signed by a responsible technical representative of the agency and counter-signed by the contractor.

8. Packaging and Shipping

8.1

During shipment the wire shall be protected and covered to prevent damage, corrosion, and entry of foreign materials.

Continuous lengths of wire shall be closely wound in layers, but adjacent turns within a layer need not be touching. The wire shall be wound so as to avoid producing kinks, waves, and sharp bends. The outside end of the spooled wire shall be so treated that it may be readily located. All coils shall be clearly identified to the approval of the purchaser.

Reeling, packaging, and shipping procedures shall be submitted to the purchaser for approval.

CAN/CSA-N285.6.6-88
Inspection Criteria for Zirconium Alloys

1. Scope

1.1

This Standard covers a series of requirements for nondestructive examinations performed at various stages of manufacture of zirconium alloy components as detailed in this series of Standards.

The requirements cover nondestructive examinations by visual, radiographic, liquid-penetrant, and ultrasonic techniques. The requirements detail applicability, requirements of the inspection, and acceptance standards.

2. NDE Personnel Qualification

2.1 General

All personnel performing nondestructive examinations to meet the requirement of the following sections shall be qualified as follows:

(a) **In Canada.** Personnel shall be qualified to CGSB Standards. The operator shall have at least a Level I certification. Only Level III personnel shall establish techniques and interpret results. When automatic inspection procedures are used, the operators shall be under the responsibility of personnel holding Level III certification.

(b) **Outside Canada.** Personnel shall be qualified to Standards acceptable to the purchaser and the regulatory authority.

2.2 Eye-Test Requirements

Where a certification scheme does not cover eye tests, evidence of satisfactory vision, as determined by an oculist, optometrist, or other professionally recognized persons shall be provided in accordance with the following requirements:

(a) distant vision shall equal 20/30 or better in at least one eye, either uncorrected or corrected;

(b) near vision shall permit reading J-1 letters on a standard Jaeger-test-type chart for near vision, or equivalent test type, in at least one eye, either uncorrected or corrected.

2.3 Documentation Control

Examination methods, procedures, and documentation control shall conform to the requirements of CSA Standard CAN3-N285.0 and to the requirements of the component specification referencing each Standard.

3. Visual-Inspection Standards

3.1 Standard V-1

3.1.1 Applicability

Typical applications for this Standard include surface examination of seamless tubes and measurement of irregularities or indications.

3.1.2 Requirements

The inspection shall meet the requirements of the *ASME Boiler and Pressure Vessel Code,* Section V, Article 9. The inspection shall be performed in an area lit to an illuminance of 2000 lx. The operator shall meet the eye test requirements of Clause 2.2. When internal surfaces of tubular products are examined, the examination shall be done using a borescope with image magnification where appropriate. The surfaces shall be free of contaminants such as grease or drawing lubricants that could obscure indications. All indications observed shall be evaluated with respect to geometry and type.

3.1.3 Acceptance Criteria

(a) All surfaces shall be free from imperfections detrimental to subsequent fabrication operations or serviceability of the components.

(b) Any indication greater than 1.5 mm, other than dents or stains, shall not be acceptable.

(c) Cracks or inclusion-type indications shall not be acceptable. Isolated minor marks or pits are acceptable if there are no sharp corners, or if their removal does not reduce the wall-thickness below the minimum specified by the purchaser. After removal by blending, the wall-thickness variation shall not exceed 0.125 mm/mm.

3.2 Standard V-2

3.2.1 Applicability

Typical applications for this Standard include the surface examinations of strip and thin-walled, large-diameter tubing, including the measurement of irregularities or indications.

3.2.2 Requirement

The inspection shall meet the requirements of the *ASME Boiler and Pressure Vessel Code*, Section V, Article 9. The inspection shall be carried out in a clean area lit to an illuminance of 2000 lx. The operator shall meet the eye test requirements of Clause 2.2. When internal surfaces of tubular products are examined, the examination shall be done using a borescope with image magnification where appropriate. The surfaces shall be free of contaminants such as grease or drawing lubricants that could obscure defect indications.

3.2.3 Acceptance Criteria

The following indications are unacceptable:

(a) All cracks, tears, and fabrication-type defects detrimental to the subsequent fabrication operations and serviceability of the components.

(b) Linear, wall-thinning defects with a depth greater than 2% of the wall thickness and a length greater than 75 mm.

(c) Linear, wall-thinning defects with a depth greater than 4% of the wall thickness and a length greater than 50 mm.

(d) Linear, wall-thinning defects with a depth greater than 6% of the wall thickness and a length greater than 25 mm.

Other indications or irregularities may be ignored if

(i) the minimum wall thickness is not affected; and

(ii) the maximum diameter or length at the surface is less than 1 mm and the maximum depth is less than 0.1 mm (the total area must be less than 1 mm^2 in any 1.25 mm length along the line of defects); and

(iii) the indication is not of Item (a) above.

Note: *If the tube ends are expanded, no surface defects greater than* 0.0125 mm *in depth are allowed in the expanded ends (including welds).*

3.3 Standard V-3

3.3.1 Applicability

Typical applications for this Standard include the surface examination of pressure tubes, including the measurement of irregularities or indications.

3.3.2 Requirements

The inspection shall meet the requirements of the *ASME Boiler and Pressure Code*, Section V, Article 9. The inspection shall be carried out in a clean area lit to an illuminance of 2000 lx. The operator shall meet the eye test requirements of Clause 2.2. The full area of the external and internal surfaces of tubular products shall be examined both by direct visual examination aided by artificial lighting and by a borescope with image magnification where appropriate. The surfaces shall be free of contaminants such as grease, oil, or drawing lubricants that could obscure defect indications.

3.3.3 Acceptance Criteria

(a) No draw marks or other blemishes shall be present in the regions within 300 mm of the ends.

(b) Isolated minor marks or shallow pits can be accepted, at the discretion of the purchaser, provided they are removed by blending using abrasive cloth techniques and the minimum wall thickness in that area still meets the minimum wall thickness stated on the drawings. The blending shall be such that the wall-thickness variation does not exceed 0.005 mm/mm. Repeat inspection shall show an absence of sharp ends.

(c) Draw marks can be accepted, at the discretion of the purchaser, in the areas at least 300 mm away from the ends, provided the minimum wall thickness specified on the drawing is met. However, the responses of the longitudinal edges and end surface (if any) of the draw mark shall be further evaluated on the ultrasonic-inspection charts, to check that the responses are characteristic of smooth blending of the draw mark with the surface. All edges with indications greater than 50% of the calibration-notch indication, as defined in Clause 6.5 of this Standard, shall be blended smooth and reexamined.

(d) When the inside surface is conditioned by honing, the surface shall be free of draw marks and other minor marks on the inside surface of the tube, as an indication of adequate surface removal.

3.4 Standard V-4

3.4.1 Applicability

Typical applications for this Standard include the surface examinations of oxidized pressure tubes, including the measurement of irregularities or inclusions.

3.4.2 Requirements

The inspection shall meet the requirements of the *ASME Boiler and Pressure Vessel Code*, Section V, Article 9. The inspection shall be carried out in a clean area lit to an illuminance of 2000 lx. The operator shall meet the eye test requirements of Clause 2.2. The full area of the external and internal surfaces of tubular products shall be examined both by direct visual examination aided by artificial lighting and by a borescope with image magnification where appropriate. The surfaces shall be free of contaminants such as grease, oil, or drawing lubricants that could obscure defect indications.

3.4.3 Acceptance Criteria

3.4.3.1 General

(a) The tubes shall show a continuous, tightly adherent, uniform black or greyish blue oxide coating. There shall be no white or brown spots showing limited oxidation more than 1.25 mm in maximum dimensions. Spots of lesser dimension spaced closer than 5 mm are also unacceptable.

Slight discolouration to the oxide caused by cleaning chemicals such as acetone are acceptable, provided the oxide remains uniform and tightly adherent.

(b) Local surface defects within 12 mm of the ends, and thus in the discard region, shall be ignored.

(c) Inspection tooling scratches that do not penetrate the oxide layer (ie, ≤0.002 mm deep) are acceptable.

(d) Shallow surface grooving or dimpling from grain structure variations are acceptable.

(e) Any cracking will be cause for rejection.

(f) The minimum wall thickness specified on the drawings shall be met in all areas.

3.4.3.2 Outside Surface Within 300 mm of Tube Ends

The following are not acceptable:

(a) scratches except as noted in Items (b) and (c);

(b) pits or similar defects greater than 0.6 mm in diameter and more than 0.0125 mm deep, spaced closer than 25 mm;

(c) proud areas, either individual or in clusters covering areas less than 300 mm^2 (these shall be dressed flush and the tube reoxidized by the autoclave process).

3.4.3.3 Outside Surface Other Than End Regions

The following are not acceptable:

(a) pits more than 3 mm in diameter and more than 0.025 mm deep (the wall thickness and oxide condition at positions of pits smaller than the above shall meet the requirements);

(b) proud areas as in Clause 3.4.3.2(c), shall be dressed flush and the tube reoxidized by the autoclave process.

3.4.3.4 Inside Surface Within 300 mm of Ends

The following are not acceptable:

(a) pits more than 1.5 mm in diameter and more than 0.0125 mm deep;

(b) scratches more than 0.005 mm deep and more than 150 mm long.

3.4.3.5 Inside Surface Other Than End Sections

The following are not acceptable:

(a) pits greater than 2 mm in diameter and more than 0.025 mm deep;

(b) scratches more than 0.025 mm deep and more than 150 mm.

4. Radiographic Standards

4.1 Standard R-1

This Standard is applicable to seam welds and heat-affected zones (HAZ) in zirconium alloy tubes. Radiography shall be in accordance with the *ASME Boiler and Pressure Vessel Code*, Section V, Article 2, with the following exception: the penetrameter shall be 0.075 mm thick and hole sizes shall be 0.125 mm, 0.25 mm, and 0.375 mm in diameter.

4.2 Acceptance Standards

The following indications are unacceptable:
(a) cavities or inclusions greater than 0.2T in diameter or length (T = weld thickness);
(b) any area of porosity greater than 0.15T mm^2 in any 12.5 mm length;
(c) in any 2T length of weld, porosity or inclusions clusters greater than 0.1T mm^2 (these clusters shall be included in the area described in Item (b);
(d) cracks, lack of fusion, undercut, incomplete penetration, and grooves.

5. Liquid-Penetrant Standards

5.1 Standard LP-1

5.1.1 Applicability

Typical applications for this Standard are the inspection of seam welds in thin-walled diameter tubing and the inspection of sheet surfaces.

5.1.2 Requirements

The examination shall be performed in accordance with the *ASME Boiler and Pressure Vessel Code*, Section V, Article 6, with the following additional requirements:
(a) Preexamination operation shall be such as not to cause defects to be masked by smearing or peening of the surface.
(b) Dye and cleaner may be applied by brushing, wiping, dipping, or spraying, but the application of developer shall be by spraying only. The propellant for any spray applications shall not be chlorinated or halogenated hydrocarbons. (CO_2, isobutane, or nitrogen are permitted.)
(c) The penetrant, developer, and cleaning materials shall each contain not more than
(i) 250 μg maximum of halogen per gram of material, as determined in a procedure that includes decomposition in accordance with ASTM Standard D808, and subsequent determination of chloride in accordance with ASTM Standard D512 and of fluorides by ASTM Standard D1179.;
(ii) 1% maximum by weight of residual sulphur when tested in accordance with ASTM Standard D129.
(d) Certification of the halogen and sulphur content to the requirements of Item (c) above shall be provided for each batch number of each material.
(e) All traces of examination materials shall be removed from the work on completion of examination by the use of acetone, alcohol, or distilled water or by other approved reagents. Final cleaning materials shall contain a maximum of 100 ppm halogens.

5.1.3 Acceptance Standards

All relevant defect indications are unacceptable. Repeat examinations after the removal of the cause of indications or repair of the surface shall show no relevant indications.

5.2 Standard LP-2

5.2.1 Applicability

This Standard typically applies to inspection of barstock and wire products.

5.2.2 Requirement

The method shall meet the requirements of ASTM Standard E165, with the additional requirements of Clause 5.1.

5.2.3 Acceptance Standards

The following relevant indications shall cause the product to be rejected:
(a) linear defects or cracks;
(b) rounded indications with dimensions greater than 0.12 mm;
(c) five or more rounded indications in any 500 mm length.

5.3 Standard LP-3

5.3.1 Applicability

This Standard typically applies to inspection of seamless tubing.

5.3.2 Requirement

The method shall meet the requirements of the *ASME Boiler and Pressure Vessel Code*, Section V, Article 6, with the additional requirements specified in Clause 5.1.

5.3.3 Acceptance Standards

The following relevant indications shall cause the tube to be rejected:
(a) linear indications or cracks;
(b) rounded indications with dimensions greater than 1.5 mm;
(c) five or more rounded indications in a line and separated by 1.5 mm or less;
(d) ten or more indications in any 40 cm^2.

6. Ultrasonic Standards

6.1 Standard U/T-1

6.1.1 Applicability

This general quality inspection Standard applies to seamless tubing such as that used for injection nozzles.

6.1.2 Requirements

Procedures shall meet the requirements of the *ASME Boiler and Pressure Vessel Code*, NB-2000 of Section III, "Tubular Products Used for Vessel Nozzles", and shall use the provisions of Standard SE 213 of the *ASME Boiler and Pressure Vessel Code*, Section V.

6.1.3 Acceptance Standards

The technique shall be selected so that its sensitivity is capable of detecting artificial U-notch defects of the following dimensions machined in calibration samples of similar material, size, and surface finish to the material to be tested:

(a) length of defect equal to 1.5 mm;
(b) depth of defect equal to 0.1 mm;
(c) width of defect less than 0.2 mm.

Defects that produce indications in excess of the indications received from calibration samples are unacceptable.

6.2 Standard U/T-2

6.2.1 Applicability

This Standard applies to the normal beam inspection of ingots.

6.2.2 Requirements

The ingot shall be machined to provide a suitable contact surface. A straight-beam contact technique on the cylindrical surface of the ingot shall be used. The examination shall comprise two axial traverses along the surface of the ingot at each of the two locations 90° apart, as described in ASTM Standard B350. The defect standard shall be a 1.60 mm diameter hole located at the centre of a similarly sized ingot section of the same material as that under test. An additional 1.60 mm diameter hole shall be located at the midradius position to allow an estimate to be made of the sensitivity of the response to hole position. The surface finish of the defect standard shall not be better than the contact surface of the ingot under test.

6.2.3 Acceptance Criteria

Defect indications greater than that received from the reference hole at the ingot centre shall be cause for rejection of that part of the ingot.

6.3 Standard U/T-3

6.3.1 Applicability

This Standard typically applies to the inspection of forged hollow billets.

6.3.2 Requirements

An ultrasonic shear-wave inspection in two circumferential directions and a normal beam inspection in the radial direction shall be performed on each machined billet. The inspection shall be done with an immersion technique with an automatic minimum 10% overlapping scan of the billet surface.

For the shear-wave inspection, a defect standard shall be fabricated from material to the same specification, shape, and surface finish as the billets to be tested and in the same heat-treatment condition or otherwise acoustically similar material, and with an outside diameter and wall thickness within ±5% of the test billets. Longitudinal notches shall be machined on the inside and outside surfaces. The inside notch shall be 6.35 ± 1.30 mm long and 0.75 ±0.01 mm deep. The outside notch shall be 6.35 ± 1.30 mm long and 0.25 ±0.01 mm deep. In addition, two side-drilled holes, less than 1.2 mm in diameter and 30 ± 10 mm deep, each centred 2.5 mm and two-thirds, respectively, of the distance from the outside to the inside surface, shall be drilled in the end of the calibration billet. One hole may be drilled in one end and the other hole in the opposite end. For the normal beam inspection, the defect standard shall have two flat-bottomed holes, 1.50 mm in diameter, drilled from the inside surface to a depth of 9.5% and 95% of the wall thickness.

The transducer(s) used to perform the shear-wave inspection shall have a focal length, frequency, beam path, and incident angle to the billet surface to assure that the sound cone scans the full section thickness during rotation and achieves optimum balance between the inside and outside notches when adjusted to give a minimum height from one notch of 70% of full scale. The response chosen for gating must demonstrate a multiple skip-type response as the notch is moved toward or away from the second entry point. The response from the side-drilled holes shall be used to provide assurance of the adequacy of the volumetric coverage during the inspection.

The normal beam inspection shall be performed by a transducer with optimum focal length, beam path, and orientation for a balanced response from the flat-bottomed holes located close to the inside and outside surfaces. If a focused probe is used, its focal point is to be about midwall. The gate must cover the echoes from both flat-bottomed holes and is to be extended to the inner surface as far as possible without obtaining indications from that surface.

6.3.3 Acceptance Criteria

Billets with indications equal to, or greater than, those of the longitudinal notches for the shear-wave inspection and the radial holes in the normal beam inspection shall be rejected.

6.4 Standard U/T-4

6.4.1 Applicability

This Standard typically applies to the volumetric inspection of rods and bars.

6.4.2 Requirements

Cylindrical rod and bar shall be examined by longitudinal waves by an immersion technique.

The defect standard shall be made from a length of bar of the same material, heat treatment, dimensions, and finish as the material to be tested. The length of the standard shall be applicable to the method of testing. The standard defect shall be a 1.6 mm diameter flat-bottomed hole drilled radially to the centre of the bar. For indications detected at other depths, other reference 1.6 mm diameter holes drilled to intermediate depths can be used to compare signal amplitudes for acceptance.

Coverage of the bars during inspection shall be 100%, with an overlap of 15% minimum.

The test instrument shall be calibrated so as to give an indication from the 1.6 mm diameter centre flat-bottomed hole at 50% of full screen height. The calibration holes shall be detected at the same inspection speed as used in production.

6.4.3 Acceptance Criteria

Any defect causing an indication greater than that from the centre flat-bottomed hole shall be cause for rejection.

6.5 Standard U/T-5

6.5.1 Applicability

This Standard typically applies to the inspection of seamless pressure tubing.

6.5.2 Requirements

The tube shall be ultrasonically inspected using an angle beam in two circumferential and two longitudinal directions and a straight beam in the radial direction. Inspection shall be done using the immersion technique with an automatic overlapping scan of the pressure-tube surface.

The "defect standard" shall be fabricated from a length of pressure tube made to the same specification with the same surface finish as the tubes to be inspected. The wall thickness shall lie within the range of wall thickness specified on the pressure-tube drawing. Detailed drawings of the calibration "defect standard" shall be included in the procedures submitted for approval by the purchaser.

For the angle-beam test, inside and outside longitudinal and circumferential calibration U-shaped notches shall be provided. The notches shall be 6.35 ± 1.30 mm long and 0.75 ± 0.01 mm deep. Each search unit shall be adjusted to produce an optimum balance in response between inside and outside notches, and the responses shall be adjusted to give a minimum height from one notch of 70% of full scale. The response chosen for gating must demonstrate a multiple skip-type response as the notch is moved toward or away from the sound entry point. The scanning overlap shall be such that each reference notch shall be detected at least twice on a run at feed speeds equal to those used in production testing.

An additional series of reference notches 6.35 ± 1.30 mm long by 0.150 mm deep shall also be provided, and the calibration shall be such that the response from these notches exceeds 100% of full scale.

No reject or suppression shall be used on the test equipment, and indications less than 20% of full scale need not be investigated. All indications greater than 20% shall be investigated by manually moving the tube to obtain the maximum response.

For the normal beam test, five flat-bottomed slots shall be machined from the inside surface. The slots shall be 0.75 ± 0.015 mm wide and 1.50 ± 0.015 mm long and shall be machined from the inside surface to a depth of 15%, 30%, 50%, 70%, and 85% of the tube-wall thickness.

The backwall reflection shall be adjusted to 100% of full scale and the alarm level shall be set at 50% level or higher. Calibration runs at the inspection speed shall indicate all notches at the alarm-level setting.

6.5.3 Acceptance Criteria

For the shear-wave examination, all tubes with indications equal to or greater than the amplitude level represented by a line drawn between the response from the 0.075 mm ID and OD notches shall be rejected. For the normal beam examination, all indications below the alarm-level setting shall be manually investigated to obtain maximum loss of backwall reflection. All tubes with backwall reflection attenuated to 30% of screen height or less shall be rejected.

6.6 Standard U/T-6

6.6.1 Applicability

This Standard typically applies to the inspection of seam-welded, thin-walled, large-diameter tubing such as calandria tubing.

6.6.2 Requirements

The inspection shall consist of a transverse and longitudinal shear-wave inspection of the tube by an immersion technique. Line or spot-focus technique shall be required. The inspection is done prior to any end-belling. The examination shall be in accordance with NB2560 of the *ASME Boiler and Pressure Vessel Code*, Section III and this Standard.

A calibration standard consisting of transverse and longitudinal ID and OD U-shaped notches shall be used. These notches shall be 0.75 mm long by 0.075 mm deep by 0.125 mm wide. The defect standard shall be fabricated from material the same as the tubing to be tested, with a surface finish similar to the tubing to be tested.

Each search unit shall be adjusted to produce an optimum balance of response between inside and outside notches and the responses shall be adjusted to give a response height from one notch of 70% of full scale.

The manufacturer shall select other parameters affecting the sensitivity of the examination and shall demonstrate to the satisfaction of the purchaser that the examination provides adequate discrimination and repeatability in the production examination mode.

6.6.3 Acceptance Criteria

Only indications that provide a response greater than 70% of the reference response level shall be investigated. The location, approximate size, and identity of all such reflectors shall be determined and evaluated as follows:

(a) all discontinuities interpreted to be cracks shall be unacceptable;

(b) surface discontinuities, other than cracks, with a response level equal to, or less than, the reference response level shall be acceptable;

(c) indications with a response level greater than the reference response level shall be unacceptable unless proven to be acceptable to Clause 3.2.3 of CSA Standard CAN/CSA-N285.6.6;

(d) indications that can be shown to be attributable to the macrostructure or microstructure of the material shall be acceptable.

National Standard of Canada CAN/CSA-N285.6.7-88

Zirconium Alloy Design Data

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CAN/CSA-N285.6.7-88
Zirconium Alloy Design Data

1. Scope

1.1

This Standard provides the physical and mechanical property data to be used for design purposes for the zirconium alloy components defined in this series of Standards.

2. General

2.1

The properties of zirconium components are specified in Tables 7.1 to 7.4. The properties of zirconium components depend on the direction of testing and therefore the design data are referenced to orientation within the component. For mechanical property data the reference data in Table 7.1 are based on the orientation that provides the lowest value.

Table 7.1
Design Stress Values for Zirconium Alloys (Sm)

Alloy	Standard	Product form	Condition	*Min yield strength, MPa	Min. UTS, MPa	Allowable stress, MPa, for metal temperature, °C									
						20	50	100	150	200	250	300	350	400	500
R60802	N285.6.1	Seamless tubing	Extruded, cold-worked (15-25%) + 400°C/24 h stress relief	270 (300°C)	330 (300°C)	192.8	181.0	160.4	143.1	129.3	119.0	110.0	101.0	91.4	68.7
R60901	N285.6.1	Seamless tubing	Extruded, cold-worked (20-30%) + 400°C/24 h stress relief	330 (300°C)	435 (300°C)	221.8	211.4	192.9	176.4	157.9	152.9	145.0	135.9	119.8	62.4
				330 (300°C)	460 (300°C)	230.1	219.7	201.2	184.7	166.2	161.2	153.3	144.2	128.1	70.7
				330 (300°C)	480 (300°C)	236.8	226.4	207.9	191.4	172.9	167.9	160.0	150.9	134.8	77.4
R60901	N285.6.1	Seamless tubing	Extruded, heat-treated (880°C W.Q.), cold-worked 10-15%, aged 500°C/24 h	450 (300°C)	540 (300°C)	260.6	251.7	233.8	218.9	204.8	191.7	180.0	168.2	154.5	107.6
R60802 R60804	N285.6.2	Seamless tubing	Annealed	240 (20°C)	415 (20°C)	138.3	129.2	114.1	97.5	83.7	72.0	63.0	56.6	52.7	45.8
R60802 R60804	N285.6.3	Seamless tubing	Extruded & annealed	240 (20°C)	415 (20°C)	138.3	129.2	114.1	97.5	83.7	72.0	63.0	56.6	52.7	45.8
R60802 R60804	N285.6.4	Seam-welded, thin-walled, large-dia. tubing	Annealed	300 (20°C)	415 (20°C)	138.3	129.2	114.1	97.5	83.7	72.0	63.0	56.6	52.7	45.8
				320(T) 320(L)	415(T) 425(L)	138.3	129.2	114.1	97.5	83.7	72.0	63.0	56.6	52.7	45.8
R60902†	N285.6.5	Wire	Quenched & aged (860°C + 570°C/7 h)	620 (20°C)	760 (20°C)	253.3	242.2	223.6	205.7	188.4	171.9	158.8	151.9	142.9	80.9

**0.2% offset yield strength*
†UNS alloy number applied for

Table 7.2
Elastic Moduli of Zirconium Alloy

Alloy	Standard	Product form	Condition	Property	Direction	Temperature, °C 20	50	100	150	200	250	300	400	500
R60802	N285.6.1	Seamless tubing	Extruded, cold-worked (15-25%) + 400°C/24 h stress relief	Young's modulus (GPa)	Long.	94.8	92.6	88.9	85.3	81.6	77.9	74.2	66.9	59.5
					Trans.	98.9	97.3	94.7	92.0	89.4	86.7	84.1	78.7	73.4
				Shear modulus (GPa)	Long.	34.0	33.4	32.2	31.1	29.9	28.8	27.6	25.4	23.0
					Trans.	35.3	34.7	33.6	32.6	31.5	30.5	29.4	27.3	25.2
				Poisson's ratio	Long.	.378	.374	.368	.361	.355	.349	.341	.328	.328
					Trans.	.393	.396	.400	.405	.410	.415	.420	.429	.439
R60901	N285.6.1	Seamless tubing	Extruded, cold-worked (20-30%) + 400°C/24 h stress relief	Young's modulus (GPa)	Long.	94.6	92.5	88.9	85.4	81.8	78.3	74.7	67.6	60.5
					Trans.	101.9	100.4	98.0	95.6	93.1	90.7	88.3	83.4	78.6
				Shear modulus (GPa)	Long.	34.5	33.8	32.6	31.4	30.3	29.1	27.9	25.6	23.2
					Trans.	35.1	34.5	33.5	32.5	31.5	30.5	29.5	27.5	25.6
				Poisson's ratio	Long.	.389	.389	.387	.384	.379	.371	.361	.340	.310
					Trans.	.457	.463	.472	.481	.489	.498	.507	.525	.542
R60901	N285.6.1	Seamless tubing	Extruded, heat-treated (880°C W.Q.), cold-worked 10-15%, aged 500°C/24 h	Young's modulus (GPa)	Long.	95.7	93.7	90.5	87.2	84.0	80.7	77.4	70.9	64.4
					Trans.	97.9	96.2	93.4	90.7	87.0	85.1	82.3	76.8	71.2
				Shear modulus (GPa)	Long.	34.5	33.9	32.7	31.6	30.5	29.3	28.2	25.9	23.6
					Trans.	34.9	34.2	33.1	32.0	31.0	29.9	28.8	26.7	24.5
				Poisson's ratio	Long.	.387	.386	.384	.382	.379	.377	.375	.371	.366
					Trans.	.394	.386	.384	.382	.386	.393	.401	.426	.458
R60802 R60804	N285.6.2	Seamless tubing	Annealed	Young's modulus (GPa)	Long.	94.8	92.6	88.9	85.3	81.6	77.9	74.2	66.9	59.5
					Trans.	98.9	97.3	94.7	92.0	89.4	86.7	84.1	78.7	73.4
				Shear modulus (GPa)	Long.	34.0	33.4	32.2	31.1	29.9	28.8	27.6	25.4	23.0
					Trans.	35.3	34.7	33.6	32.6	31.5	30.5	29.4	27.3	25.2
				Poisson's ratio	Long.	.378	.374	.368	.361	.355	.349	.341	.328	.328
					Trans.	.393	.396	.400	.405	.410	.415	.420	.429	.439

(Continued)

Table 7.2 (Concluded)

Alloy	Standard	Product form	Condition	Property	Direction	Temperature, °C 20	50	100	150	200	250	300	400	500
R60802 R60804	N285.6.3	Seamless tubing	Extruded & annealed	Young's modulus (GPa)	Long.	94.8	92.6	88.9	85.3	81.6	77.9	74.2	66.9	59.5
					Trans.	98.9	97.3	94.7	92.0	89.4	86.7	84.1	78.7	73.4
				Shear modulus (GPa)	Long.	34.0	33.4	32.2	34.1	29.9	28.8	27.6	25.4	23.0
					Trans.	35.3	34.7	33.6	32.6	31.5	30.5	29.4	27.3	25.2
				Poisson's ratio	Long.	.378	.374	.368	.361	.355	.349	.341	.328	.328
					Trans.	.393	.396	.400	.405	.410	.415	.420	.429	.439
R60802 R60804	N285.6.4	Seam-welded, large-dia., thin-walled tubing D/T~100	Annealed	Young's modulus (GPa)	Long.	94.0	92.1	89.0	86.0	82.8	79.6	76.5	70.1	63.8
					Trans.	95.8	93.6	90.6	87.8	84.8	81.9	79.0	73.1	67.1
				Shear modulus (GPa)	Long.	34.5	33.7	32.6	31.4	30.2	29.0	27.8	25.5	23.1
					Trans.	35.7	35.1	33.8	32.8	31.5	30.4	29.2	26.8	24.5
				Poisson's ratio	Long.	.375	.375	.375	.375	.377	.380	.380	.385	.390
					Trans.	.345	.345	.345	.347	.350	.355	.360	.362	.367
R60902	N285.6.5	Wire	Quenched & aged (860°C + 570°C/7 h)	Young's modulus (GPa)	Long.	95.7	93.7	90.5	87.2	84.0	80.7	77.4	70.9	64.4
				Shear modulus (GPa)	Long.	34.5	33.9	32.7	31.6	30.5	29.3	28.2	25.9	23.6
				Poisson's ratio	Long.	.387	.386	.384	.382	.379	.377	.375	.371	.366

Table 7.3
Thermal Expansion Data for Zirconium Alloys

Alloy	Standard	Product form	Condition	Direction	Coefficient fo thermal expansion 0-300°C	400°C	450°C	500°C	Equation describing expansion
R60802	N285.6.1	Seamless tubing	Extruded, cold-worked (15-25%) + 400°C/24 h stress relief	Long.	5.0	5.0	5.0	5.0	$\Delta L/L = 5.0 \times 10^{-6}\ \Delta T$
				Trans.	7.9	7.9	7.9	7.9	$\Delta L/L = 7.9 \times 10^{-6}\ \Delta T$
R60901	N285.6.1	Seamless tubing	Extruded cold-worked (20-30%) + 400°C/24 h stress relief	Long.	5.1	3.26	2.89	2.14	$\Delta L/L = -0.38 \times 10^{-4} + 5.86 \times 10^{-6}\ \Delta T + 3.72 \times 10^{-9}\ \Delta T^2$
				Trans.	6.9	6.9	6.9	7.6	$\Delta L/L = 6.9 \times 10^{-6}\ \Delta T$
R60901	N285.6.1	Seamless tubing	Extruded, heat-treated (880°C, W.Q.), cold-worked 10-15%, aged 500°C/24 h	Long.	6.0	6.0	6.0	6.0	$\Delta L/L = 6.0 \times 10^{-6}\ \Delta T$
				Trans.	6.0	6.0	6.0	6.0	$\Delta L/L = 6.0 \times 10^{-6}\ \Delta T$
R60802 R60804	N285.6.2	Seamless tubing	Annealed	Long.	5.2	5.2	5.2	5.2	$\Delta L/L = 5.2 \times 10^{-6}\ \Delta T$
				Trans.	NA				
R60802 R60804	N285.6.3	Seamless tubing	Extruded and annealed	Long.	NA*				
				Trans.	NA				
R60802 R60804	N285.6.4	Seam-welded, thin-walled large-dia. tubing D/T~100	Annealed	Long.	5.3	5.3	5.3	5.3	$\Delta L/L = 5.3 \times 10^{-6}\ \Delta T$
				Trans.	6.8	6.8	6.8	6.8	$\Delta L/L = 6.8 \times 10^{-6}\ \Delta T$
R60902	N285.6.5	Wire	Quenched and aged 860°C + 570°C/7 h	Drawing	6.0†	6.0†	6.0†	6.0†	$\Delta L/L = 6.0 \times 10^{-6}\ \Delta T$

**Data not available. Data of CSA Standard CAN/CSA-N285.6.2 would be close approximation.*
†Data not available. Assumed to be in same as HT.Zr.2.5 Nb.
Note: *The thermal expansion characteristics of zirconium alloys are anisotropic and depend on the product form (tubing, plate, etc) and on the texture (ie, the result of the method of working, intensity of working, heat treatment). The data shown in the above table represents the materials currently used in CANDU reactor components, but they should be used with caution. The data show that below 300°C practically all forms of zircalloy-2 and Zr. 2.5 Nb have a linear thermal expansion with temperature. Only on one component direction was there a deviation from linearity below 500°C.*

Table 7.4
Thermal Conductivity Data for Zirconium Alloys

Alloy	Standard	Product form	Condition	Tube Direction	Thermal conductivity, W/(m·K), for metal temp, °C									
					20	50	100	150	200	250	300	350	400	500
R60802	N285.6.1	Seamless tubing	Extruded, cold-worked (15-25%) + 400°C/72 h stress relief	Radial circumf. axial	13.3 11.9 13.4	13.5 12.2 13.7	13.9 12.7 14.3	14.2 13.2 14.9	14.5 13.7 15.4	15.0 14.2 16.0	15.4 14.7 16.6	15.9 15.2 17.2	16.4 15.7 17.7	17.4 16.7 18.9
R60901	N285.6.1	Seamless tubing	Extruded, cold-worked (20-30%) + 400°C/24 h stress relief	Radial circumf. axial	17.0 17.4 17.7	17.0 17.3 17.6	17.2 17.1 17.5	17.2 17.2 17.7	17.6 17.6 18.1	17.8 17.9 18.5	18.2 18.3 18.8	18.5 18.7 19.2	18.9 19.0 19.5	19.6 19.7 20.3
R60901	N285.6.1	Seamless tubing	Extruded, heat-treated (880°C,W.Q), cold-worked 10-15%, aged 500°C/24 h	Radial circumf. axial	17.0 16.9 16.9	16.9 17.0 17.0	17.0 17.1 17.1	17.0 17.3 17.3	17.1 17.5 17.7	17.4 17.8 18.0	17.7 18.1 18.3	18.1 18.4 18.7	18.4 18.8 19.1	19.3 19.6 20.1
R60802 R60804	N285.6.2	Seamless tubing	Annealed	Radial circumf. axial	* * *									
R60802 R60804	N285.6.3	Seamless tubing	Extruded and annealed	Radial circumf. axial	* * *									
R60802 R60804	N285.6.4	Seam-welded, thin-walled, large-dia. tubing	Annealed	Radial cirumf. axial	12.7 13.6 12.9	12.9 14.1 13.3	13.2 14.8 14.0	13.6 15.6 14.7	13.9 16.3 15.4	14.4 17.1 16.1	14.8 17.8 16.8	15.3 18.5 17.6	15.8 19.3 18.3	17.0 20.8 20.6
R60902†	N285.6.5	Wire	Quenched & aged (860°C + 570°C/7 h)	Axial	17.8	18.0	18.3	18.5	18.8	19.1	19.4	19.7	19.9	20.5

**Assumed to be the same as data for CSA Standard CAN/CSA-N285.6.4. Alternatively, thermal conductivity for zirconium alloys can be calculated from the measured electrical resistivity according to the relationship* $\lambda = 1.69 + 2.81 \times 10^{-8} T/\rho$

where

λ = *thermal conductivity,* W/(m·K)

T = *temperature,* K

ρ = *electrical resistivity,* $\mu\Omega$

†UNS alloy number applied for.

National Standard of Canada CAN/CSA-N285.6.8-88

Martensitic Stainless Steel for Fuel-Channel End Fittings

Prepared by
Canadian Standards Association

Approved by
Standards Council of Canada

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CAN/CSA-N285.6.8-88
Martensitic Stainless Steel for Fuel-Channel End Fittings

1. Scope

1.1

This Standard covers the technical requirements for martensitic stainless steel for components of a CANDU reactor, in particular the fuel-channel end fittings.

2. Definitions

The following definitions apply in this Standard:

Billet—the hot-worked product of one ingot intermediate between the ingot and the forging blank or raw extrusion.

Raw extrusion—the total length of material emerging from the extrusion press as one piece.

Blank—the length of forging (forging blank) or raw extrusion (extrusion blank) that is to be used for the manufacture of one component.

3. Production of Blanks

3.1 Quality Standards

The material shall be manufactured in accordance with the quality Standards specified in the contractual documents.

3.2 Material

3.2.1 Production Processes

The steel shall be produced by the electric-furnace process. Remelting processes are acceptable. The blank may be produced by forging or extruding.

3.2.2 Material Composition

The steel shall be a modified Type 403 martensitic stainless steel of the following composition:

Carbon	0.10–0.14%
Manganese	0.50–0.70%
Phosphorus	0.030% max.
Sulphur	0.010% max.
Chromium	11.7–12.5%
Nickel	0.10–0.40%
Silicon	0.10–0.40%
Cobalt	0.025% max.
Boron	0.002% max.
Copper	0.20% max.

3.2.3 Design Data

Design data for this material are given in the following Tables:

8.1—Mechanical Properties
8.2—Design Stress Intensity Values
8.3—Moduli of Elasticity
8.4—Thermal Expansion Data
8.5—Thermal Conductivity Data

3.3 Requirements for Blanks

3.3.1 Heat Treatment of Blanks

Blanks shall be rough-machined and bored before heat treatment. The blanks shall be hardened by quenching and shall then be tempered for a minimum of 4 h at a minimum temperature of 600°C.

3.3.2 Surface Finish

The surface of each blank shall be cleaned free of scale, using an appropriate cleaning method approved by the purchaser. The surface shall be sufficiently smooth and free of scale to permit ultrasonic examination as specified in Clause 3.4.5.

3.3.3 Quality of Blanks

3.3.3.1 General

The blanks shall be uniform in quality and free from all injurious discontinuities such as cracks, laps, seams, and voids.

3.3.3.2 Material Homogeneity

Billets, raw extrusions, and blanks shall be examined for material homogeneity by macroetch examination as specified in Clause 3.4.3.

3.3.3.3 Material Continuity

Each blank shall be ultrasonically examined as required by Clause 3.4.5. In addition, each blank shall be capable of meeting the requirements for liquid-penetrant or magnetic-particle examination, after final machining, as specified in Clause 3.4.5.

The boss section and surrounding area of each blank shall be given a preliminary liquid-penetrant or magnetic-particle test, after heat treatment, to ensure freedom from all injurious discontinuities as described in Clause 3.3.3.1.

3.3.4 Repair and Straightening

Repair of any defect by welding is not permitted. Straightening of heat-treated blanks that are bowed more than 3 mm/m of length shall be done only after approval by the purchaser. Blanks that are bowed 3 mm/m of length and less may be straightened at 250–300°C. The total holding time at the straightening temperature shall not exceed 4 h.

3.3.5 Identification of Blanks

Each blank shall be marked on one end by the manufacturer with a serial number, which shall identify the heat number, ingot number, and position in the ingot. An extrusion blank, after cutting, shall have an additional identification to indicate its position in the raw extrusion.

3.3.6 Mechanical Property Requirements

3.3.6.1 General

Test prolongations taken from quenched and tempered blanks in accordance with the requirements of Clause 3.4.4.1 shall be given a further stress-relief treatment, in accordance with Clause 3.4.4.2.

3.3.6.2 Tensile Properties

The heat-treated and stress-relieved material shall have the following tensile properties, in the transverse direction, at room temperature, when tested in accordance with Clause 3.4.4:

Ultimate tensile strength	725 MPa min.
Yield strength (0.2% offset)	585 MPa min.
Elongation in 50 mm (2 inches)	12% min.
Reduction in area	30% min.

3.3.6.3 Impact Properties

The method of impact testing shall be as stated in Clause 3.4.4.

The material, after heat treatment and stress relieving, shall have the following absorbed energy levels:

Longitudinal	27 J min. individual value at 21°C max.
Transverse	20 J min. individual value at 65°C max.

The lateral expansion in mils and percentage shear fracture shall be reported.

3.3.6.4 Hardness Properties

The heat-treated blanks shall have a hardness of BHN 223-269 when tested as stated in Clause 3.4.4.

3.4 Inspections, Examinations, Tests, and Reports

3.4.1 General

The material shall meet the acceptance criteria of the following inspections, examinations, and tests.

3.4.2 Chemical Analysis

Mill certificates are required covering the ladle analysis of each heat of steel used. In addition, a product analysis shall be done on each blank sample selected for mechanical testing as specified in Clause 3.4.4.

Both ladle and product analyses shall meet the material composition requirements of Clause 3.2.2. There shall be no tolerances applied to the limits stated in Clause 3.2.2 on either ladle or product analysis. The maximum levels for phosporous, nickel, cobalt, and copper shall be considered especially significant.

Certified Material Test Reports shall be submitted, as required by Section III of the *ASME Boiler and Pressure Vessel Code*, Article NCA 3000, "Metallic Material Manufacturer's and Material Supplier's Quality System Program; Examinations, Tests, and Reports".

3.4.3 Macroetch Examination

3.4.3.1 General

Samples from billets, raw extrusions, and blanks that have been selected as detailed in Clause 3.4.3.2 shall be macroetched as required by Clause 3.4.3.3. Failure of any macroetch specimen to meet the

acceptance requirements of Clause 3.4.3.4 shall be cause for rejection of the material represented by that sample.

3.4.3.2 Samples

A sample slice shall be cut from the end of the billet or raw extrusion that represents the material closest to the top of each ingot.

In addition, the end of the prolongation on each blank selected for mechanical tests for strength as described in Clause 3.4.4 shall be used as a sample. All samples shall show a full cross-section of the billet, raw extrusion, or blank to be tested.

3.4.3.3 Examination Procedure

The surface of the sample shall be ground and deep-etched in accordance with the requirements of ASTM Standard E381.

3.4.3.4 Acceptance Requirements

The quality and cleanliness of the billets shall be equal to or better than macrographs S2-R1-C1 of ASTM Standard E381. The quality of the steel in raw extrusions and blanks shall be equal to or better than S2-R1 of ASTM Standard E381. Ring defects shall not extend beyond the midradius of blanks. In addition, the following apply:

(a) In billets, centre segregations in excess of C1 that can be contained within a 50 mm diameter circle shall be acceptable on the basis that they will be removed when machining the bore.

(b) If any billet or raw extrusion sample fails to meet the above acceptance criteria, the top of the billet or raw extrusion may be cut back a suitable amount. A new sample slice, representing material closest to the top of the ingot, shall be macroetched and examined to determine the acceptability of the remaining portion of the billet or raw extrusion.

(c) If any blank fails to meet the above acceptance criteria, the other blanks produced from the same billet may be individually macroetched at the end nearest to the top end of the billet and examined to determine their acceptability.

3.4.4 Mechanical Tests—Tensile, Impact, and Hardness Tests

3.4.4.1 General

Tensile and impact tests shall be performed on the material taken from one blank from each mill heat in each heat-treatment lot. All blanks shall be tested for hardness. Failure of the material to meet the acceptance requirements stated in Clause 3.4.4.4 shall be cause for rejection of the heat-treatment lot it represents.

3.4.4.2 Specimens for Mechanical Tests

3.4.4.2.1 Specimens for Tensile and Impact Tests

3.4.4.2.1.1

The blank selected for testing in accordance with Clause 3.4.4.1 shall have a full-size prolongation of at least 10 cm in length. It shall be identified with the serial number of the blank and shall be cut from the end after quenching and tempering. After parting, the prolongations shall receive further heat-treatment representative of the stress-relief heat-treatment given to the component before the final machining operation. The stress relief heat-treatment shall be as follows:

(a) load into a furnace preheated to 300°C max.;

(b) raise the temperature at a rate of 100°C per hour to 565 ± 15°C;

(c) hold temperature at 565 ± 15°C for 2 h; and

(d) air-cool.

3.4.4.2.1.2

The test program shall include the following:

(a) One tensile test specimen with its major axis perpendicular to the blank axis shall be cut from each prolongation. The prolongation and the location of the prolongation shall meet the requirements specified in Section III of the *ASME Boiler and Pressure Vessel Code*, Article NB-2000, "Procedure for Obtaining Test Coupon and Specimens from Quenched and Tempered Material Forgings". The type of specimen shall be a standard 12.5 mm round tension-test specimen with 50 mm gauge length as specified in Specification SA-370, *ASME Boiler and Pressure Vessel Code*, Section II, Part A.

(b) Six impact test specimens shall be cut from a location that meets the requirements specified in Section III of the *ASME Boiler and Pressure Vessel Code*, Article NB-2000, "Impact Test Procedures". Three impact test specimens shall be cut with their major axis parallel to the blank axis. The other three shall have their axis perpendicular to the blank axis. The length of the notch of the specimens shall be perpendicular to the surface of the blank. The type of specimen shall be Charpy V-notch Type A (10 × 10 mm) as specified in the *ASME Boiler and Pressure Vessel Code*, Section II, SA-370. Pieces

from which specimens have been cut and the specimens themselves shall be retained for a specified period of time.

3.4.4.2.2 Specimens for Hardness Testing

Each blank shall be hardness-tested following heat treatment, descaling, and cleaning.

3.4.4.3 Procedures for Mechanical Testing

3.4.4.3.1 Tensile Tests

The tensile test shall be performed in accordance with the *ASME Boiler and Pressure Vessel Code*, Section II. Testing shall be done at 21°C. The following measurements shall be recorded:

(a) ultimate tensile strength;
(b) yield strength at 0.2% offset;
(c) elongation in 50 mm gauge length; and
(d) percent reduction in area.

3.4.4.3.2 Impact Tests

Three longitudinal impact tests at 21°C maximum and three transverse impact tests at 65°C maximum shall be performed. Testing procedure shall conform to the *ASME Boiler and Pressure Vessel Code*, Section II, SA-370. The type of specimen shall be Charpy V-notch Type A (10×10 mm) as specified in the *ASME Boiler and Pressure Vessel Code*, Section II, SA-370.

Lateral expansion and percent shear fracture shall be determined by the methods and gauges recommended in the *ASME Boiler and Pressure Vessel Code*, Section II, SA-370. The following measurements shall be recorded:

(a) absorbed energy level in joules;
(b) lateral expansion in mils; and
(c) percent shear fracture.

3.4.4.3.3 Hardness Tests

The hardness of each blank shall be tested by one of the methods recommended in the *ASME Boiler and Pressure Vessel Code*, Section II, SA-370. Hardness shall be measured at a minimum of four locations on the periphery of the blank, including each end and the centre of the blank. The Brinell hardness number shall be recorded.

3.4.4.4 Acceptance Requirements

3.4.4.4.1 Tensile Tests

The results of the tensile test shall meet the requirements of Clause 3.3.6.2.

3.4.4.4.2 Impact Tests

The results of the impact tests shall meet the requirements of Clause 3.3.6.3.

3.4.4.4.3 Hardness Tests

Hardness tests results shall meet the requirements of Clause 3.3.6.4.

3.4.4.5 Retest

If any test specimen shows defective machining, it may be replaced by a specimen taken as near to the original specimen as possible. If a test failure occurs because of the development of a flaw in the test specimen during testing, a retest shall be allowed if the cause of the flaw is identified and the Engineer responsible for the component is notified. If any result of the mechanical tests of any test lot fails to meet the acceptance requirements of this Standard, the lot may be re-heat treated. No more than three heat-treatment cycles shall be performed.

3.4.5 Nondestructive Examination

3.4.5.1 Visual Examination

Each blank shall be visually examined according to the requirements of Clause 3.1.2 of CSA Standard N285.6.6 to verify conformance to the requirements of Clause 3.3.3.1.

3.4.5.2 Dimensional Examination

Each blank shall be examined dimensionally to verify conformance to the relevant drawings for the blanks.

3.4.5.3 Ultrasonic Examination

Each blank shall be ultrasonically examined after heat-treatment, in the as-finished condition, in accordance with the *ASME Boiler and Pressure Vessel Code*, Section III, Class 1, Article NB-2000, "Requirements for Wrought Seamless Fittings"; and in accordance with the following requirements:

(a) **Examination Procedure.** Angle-beam examination shall be performed from the outside surface in the clockwise and anticlockwise circumferential directions and both axial directions, to ensure detection of longitudinally and transversely oriented discontinuities. In the examination, the following apply:

(i) Immersion ultrasonic techniques shall be used where practical.

(ii) Straight-beam examination shall be used in areas where the angle-beam technique does not give complete coverage.

(iii) Angle-beam and straight-beam examinations shall be done in accordance with the *ASME Boiler and Pressure Vessel Code*, Section II, SA-388.

(iv) *Calibration Procedure:* The calibration reference specimen shall be fabricated from blank material of the same nominal diameter as the production blanks. The angle-beam reference specimen shall consist of both internal and external, longitudinal and transverse (circumferential) notches. These notches shall be square-bottomed grooves with a depth of 5% of the nominal wall thickness of the finished machined component, ie, 0.65 mm deep, 12.5 mm long, and 1.6 mm wide. The straight-beam reference specimen shall be flat-bottomed drilled holes, 2.5 mm in diameter, located at 1/3 and 2/3 depths of the thickest section to be examined.

(v) An amplitude reference line shall be drawn between the signals obtained from the drilled holes or notches, set to approximately 75% of full screen height.

(vi) Discontinuity indications equal to or exceeding 50% of the amplitude reference line shall be recorded.

(b) **Acceptance Requirement.** Indications equal to or exceeding the amplitude reference line shall be cause for rejection of the blank.

3.4.5.4 Liquid-Penetrant/Magnetic-Particle Examination

Liquid-penetrant or magnetic-particle examination of each component will be performed after final machining. Liquid-penetrant and magnetic-particle examination shall be performed in accordance with Section III of the *ASME Boiler and Pressure Vessel Code*, Article NB-2000, "Examination and Repair of Forgings and Bars".

3.4.5.5 Qualifications of Nondestructive Examination Personnel

All personnel performing nondestructive examination to meet the requirements of this Standard shall be qualified as detailed in CSA Standard N285.6.6, Clause 2.

3.4.6 Inspection and Test Failure

The provisions for retest, retreatment, or rejection of blanks due to failure on inspection or test shall be as outlined in the appropriate requirement of Clause 3.4.

3.5 Packaging and Shipping

The contractor shall make adequate provision to protect the blanks supplied to the requirements of this Standard, to ensure that on arrival at the destination specified in the pertinent contractual documents, the blanks will not be damaged.

Table 8.1
Mechanical Properties*

Temperature, °C	Ultimate tensile strength, MPa, min.	Yield strength, MPa, min.
20	725	585
50	725	583
100	725	555
150	708	538
200	697	524
250	686	510
300	674	498
350	662	486

**Prorated and interpolated from values given in Table 1 of the* ASME Boiler and Pressure Vessel Code *Case 1337-11, May 15, 1978, to reflect transverse tensile property requirements.*

Table 8.2
Design Stress Intensity Values*

Temperature, °C	Allowable stress, Mpa
20	241
50	241
100	241
150	236
200	232
250	229
300	225
350	221

**Based on one-third of minimum ultimate tensile strength (Table 8.1).*

Table 8.3
Moduli of Elasticity (Young's Moduli)*

Temperature, °C	Modulus of elasticity, E ($\times 10^5$ MPa)
20	2.01
50	2.00
100	1.98
150	1.95
200	1.92
250	1.89
300	1.81
350	1.74

**Interpolated from Table I-6.0, Appendix I, Section III,* ASME Boiler and Pressure Vessel Code, *1977 edition, Summer 79 Addenda.*

Table 8.4
Thermal Expansion Data

Temperature, °C	Mean coefficient of thermal expansion from 21°C to the indicated temperature ($\times 10^{-6}$/°C)		
	ASME Code*	Measured values	
		Extrusion	Forging
50	10.8	8.4	7.4
75	11.0	9.1	8.1
100	11.1	9.7	8.7
125	11.2	10.2	9.3
150	11.3	10.5	9.8
175	11.4	10.7	10.1
200	11.5	10.9	10.4
225	11.6	11.1	10.7
250	11.6	11.3	10.9
275	11.7	11.5	11.1
300	11.7	11.7	11.3
325	11.8	11.8	11.5
350	11.8	11.9	11.7

**Interpolated from Table I-5.0, Appendix I, Section III,* ASME Boiler and Pressure Vessel Code, *1977 edition, Summer 79 Addenda.*

Table 8.5
Thermal Conductivity Data

Temperature, °C	Thermal coefficient of thermal conductivity, W/(m·K)
20	25.32
50	25.51
75	25.66
100	25.80
125	25.95
150	26.10
175	26.27
200	26.41
225	26.58
250	26.73
275	26.88
300	27.05

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Materials for Supports for Pressure-Retaining Items

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CAN/CSA-N285.6.9-88
Materials for Supports for Pressure-Retaining Items

1. Scope

1.1

This Standard defines materials to CSA Standards that may be used for the supports of pressure-retaining items in CANDU nuclear power plants.

2. General Requirements

2.1

The requirements of the *ASME Boiler and Pressure Vessel Code*, Section III, NF 2000, shall be met except as modified by this Standard.

2.2

Where reference is made to other Standards, the edition of such Standards shall be consistent with the requirements of CSA Standard CAN3-N285.0.

3. Materials

3.1

Materials listed in Tables 9.1 and 9.2 of this Standard may be used in constructing supports for pressure-retaining items.

3.2

Yield strengths and design stress-intensity values for materials for Class 1 supports are provided in Table 9.1.

3.3

Yield strengths and allowable stress values for materials for Class 2, 3, and 4 supports are provided in Table 9.2.

3.4

Strength values up to a temperature of 150°C (300°F) are provided in Table 9.1. Use of these materials at higher temperatures may only be considered on a special-case basis.

3.5

Rolled structural shapes are limited to those permitted for structural quality steel. Welded shapes are permitted, providing the welding meets the requirements of this Standard.

3.6

Materials shall be made to fully killed or semikilled steelmaking practice.

4. Welding

4.1

The materials shall be grouped in S-number groupings of base metals, similar to the P-number groupings in Table QW-422, *ASME Boiler and Pressure Vessel Code*, Section IX*.

**S-numbers are essentially equivalent to P-numbers. The S-number grouping concept was developed by the* ASME Boiler and Pressure Vessel Code *in Code Case N-71 to impose additional restrictions on welding performed on alternative materials.*

4.2

A welding procedure qualification with a base metal in one P-number and group-number qualifies all other base metals in the same S-number and group-number. Qualifications for S-number materials do not qualify corresponding P-number materials.

4.3

For performance qualification of welders and welding operations, the requirements for P-numbers of base metals shall also be applied to the same S-numbers of base metals within this Standard. Qualification with P-numbers in accordance with the *ASME Boiler and Pressure Vessel Code*, Section IX, QW-310.4, qualifies for corresponding S-numbers.

4.4

Welding materials used shall conform to the material specifications in the *ASME Boiler and Pressure Vessel Code*, Section II, Part C, and the requirements of *ASME Boiler and Pressure Vessel Code*, Section III, NF-2400.

4.5

Electrodes for shielded-metal arc welding shall be low-hydrogen-type electrodes as defined in the *ASME Boiler and Pressure Vessel Code*, Section II, Part C.

4.6

Preheating shall be performed in accordance with the *ASME Boiler and Pressure Vessel Code*, Section III, NF 4600, and Section III, Appendix D, Article D-1000, for the P-number corresponding to the given S-number.

5. Examination

5.1

Materials shall be examined in accordance with the *ASME Boiler and Pressure Vessel Code*, Section III, NF-2500.

5.2

Welding shall be examined in accordance with the *ASME Boiler and Pressure Vessel Code*, Section III, NF-5000.

6. Certification

6.1

Certification of material shall be in accordance with the *ASME Boiler and Pressure Vessel Code*, Section III, NF-2130, and identification of material shall be in accordance with the *ASME Boiler and Pressure Vessel Code*, Section III, NF-2150.

Table 9.1
Minimum Ultimate Tensile Strengths, Yield Strength Values (S_y), and Design Stress-Intensity Values (S_m) for Class 1 Materials Covered by This Standard

Specification	Grade	Weldability S No.	Weldability Group No.	Minimum ultimate tensile strength, MPa 0–150°C	Yield strength (S_y), MPa, metal temperature not exceeding 35°C	90°C	150°C	Design stress-intensity value (S_m), MPa, metal temperature not exceeding 35°C	90°C	150°C
Carbon Steels										
CAN3-G40.21	260W	1	1	400	250	225	220	133	133	133
	260WT	1	1	400	250	225	220	133	133	133
CAN3-G40.21	300W	1	1	410	280	240	230	137	137	137
	300WT	1	1	410	280	240	230	137	137	137
CAN3-G40.21	350W	1	1	425	320	275	265	142	142	142
	350WT	1	1	425	320	275	265	142	142	142
CAN3-G40.21	400W*	1	2	425	320	275	265	142	142	142
	400WT*	1	2	425	320	275	265	142	142	142

**The use of higher values would require substantiation by a testing program and approval by the regulatory authority.*

Table 9.2
Minimum Ultimate Tensile Strengths, Yield Strength Values (S_y), and Allowable Stress Values (S) for Class 2, 3, and 4 Materials Covered by This Standard

Specification	Grade	Weldability S No.	Weldability Group No.	Minimum ultimate tensile strength, MPa 0–150°C	Yield strength (S_y), MPa, metal temperature not exceeding 35°C	90°C	150°C	Design stress value (S), MPa, metal temperature not exceeding 35°C	90°C	150°C
Carbon Steels										
CAN3-G40.21	260W	1	1	400	250	225	220	100	100	100
	260WT	1	1	400	250	225	220	100	100	100
CAN3-G40.21	300W	1	1	410	280	240	230	103	103	103
	300WT	1	1	410	280	240	230	103	103	103
CAN3-G40.21	350W	1	1	425	320	275	265	106	106	106
	350WT	1	1	425	320	275	265	106	106	106
CAN3-G40.21	400W*	1	2	425	320	275	265	106	106	106
	400WT*	1	2	425	320	275	265	106	106	106

**The use of higher values would require substantiation by a testing program and approval by the regulatory authority.*

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