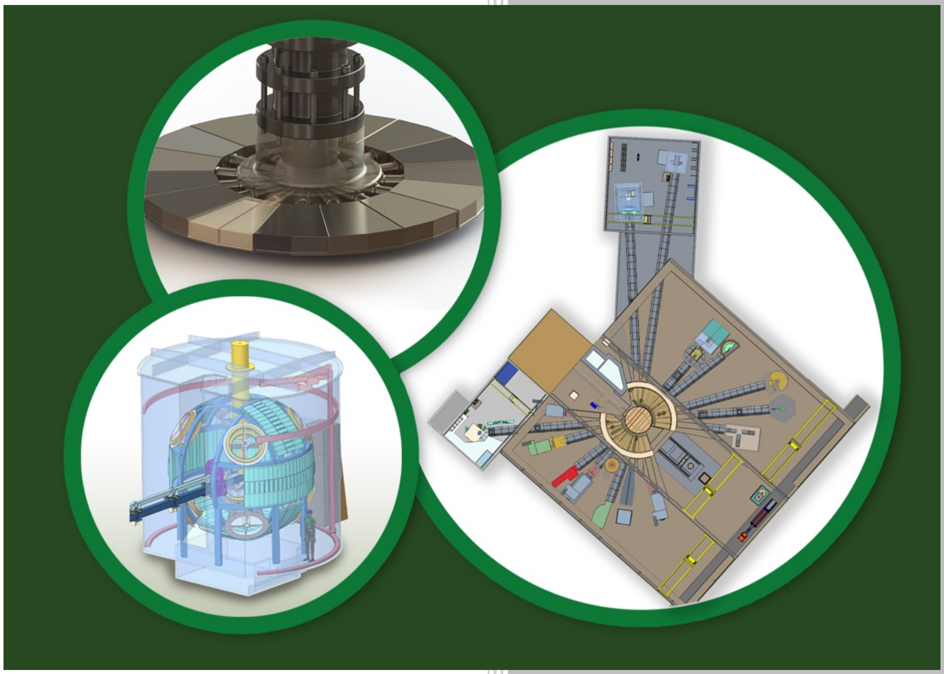
S01020000-PC0007

# Second Target Station (STS) Project Design and Fabrication of Pressure and Vacuum Systems



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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

**S01020000-PC0007**

Second Target Station (STS) Project

# Design and Fabrication of Pressure and Vacuum Systems

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# Table of Contents

## 1. PURPOSE

This document describes the design requirements for pressure systems in the Spallation Neutron Source (SNS) Second Target Station (STS) at Oak Ridge National Laboratory (ORNL). ORNL's Standards Based Management System (SBMS) classifies pressure systems as Exempt, Moderate Energy, High Energy, and Pre-Approved / Consensus Standards. This procedure defines STS's internal requirements associated with these categories. The full definition of these categories is defined by the current revision of the SBMS exhibit on Pressure System Safety (https://sbms.ornl.gov/sbms/SBMSearch/subjarea/PresSys/sa.cfm). Pressure Systems and devices must meet the requirements in place at the time in which they were designed, and need not be requalified as requirements are revised, but instead move from their as-designed energy category into the pre-approved category.

## 2. SCOPE

For the purposes of this document:

- "Pressure systems" (as defined by SMBS) includes all pressure vessels and pressure sources including cryogenics, pneumatic, hydraulic, and vacuum. Vacuum systems are considered pressure systems due to their potential for catastrophic failure due to backfill pressurization. Associated hardware (e.g., gauges and regulators), fittings, piping, pumps, and pressure relief devices are also integral parts of the pressure system.

- "Piping" is defined in ASME B31.3 as a pressure tight cylinder used to convey a fluid or to transmit a fluid pressure, ordinarily designated "pipe" in applicable material specifications.

## 3. REQUIREMENTS

All moderate and high energy pressure devices shall be indelibly labeled with their part numbers, typically by stamping, machining or etching. If labeling is not practical due to the device's size, shape, or some other reason, then the device must be "bagged or tagged." When practical, exempt systems should also be marked in this manner.

Procurement specifications and manufacturing instructions shall require maximum allowable internal and / or external working pressure to be marked with a permanent indication in the same manner, with the same caveat.

All non-exempt systems must be protected against the hazards of overpressure per SBMS exhibit on overpressure protection and as mandated by applicable codes and standards.

Energy categorization may be determined by calculating the product of maximum pressure rating times system volume (sometimes referred to in this document as the "PV method") for gases or liquids, or by using the following stored energy calculation, for gases:

$$E = \frac{P_1 V_1}{\gamma - 1}\left[1 - \left(\frac{P_0}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right]$$

*where:*

| | |
|---|---|
| E | is stored energy (kJ, BTU, or ft*lbf) |
| $P_1$ | is absolute pressure inside the vessel (kPa or bar or psi) |
| $V_1$ | is the volume of the vessel ($m^3$ or $in^3$ etc.) |
| $P_0$ | is external absolute pressure, usually atmospheric (kPa or bar or psi) |
| $\gamma$ | is the ratio of specific heats $C_P/C_V$ |

**Alternative approaches**

In cases when a system cannot meet SBMS Pressure System Safety requirements, a formal, documented hazard analysis shall be performed by the Design Engineer and approved by the Pressure Safety Subject Matter Expert. In these circumstances, Group Leader and Division Director Approval are required.

**Commercial Equipment**

Systems and devices designed to consensus codes (such as the ASME Boiler Pressure Vessel Code) may be certified as compliant by the vendor. In cases when consensus codes are not applicable, the vendor may alternatively certify that they meet the requirements in this procedure.

Systems made from commercial components with pressure ratings greater than the worst-case pressure do not require re-analysis, but must be documented by a flow diagram, pressure system schematic or P&ID (Process and Instrumentation Diagram).

**Documentation**

Drawings, schematics, diagrams, and calculations, as required by this document, shall be stored for Record Copy in the appropriate document control system.

Prior to Release for Use of a pressure system, the device must be added to the appropriate pressure system inventory.

## 3.1 EXEMPT SYSTEMS

Exempt Systems, as defined by SBMS, are not required to have a Design Analysis Calculation (DAC), but the Pressure*Volume (PV) or stored energy calculation should be documented within the design process control system used at the time of the calculation (for example, at the time this document was written, the Instrument Engineering group was using eMOD for Design Process control).

## 3.2 MODERATE ENERGY SYSTEMS

Vacuum Systems that are backfilled shall be classified as High Energy Systems if their PV ≥ 73 $ft^3$*psi or stored energy is ≥ 10,000 ft-lbs (13,560 joules), even if their maximum internal pressure during backfilling is less than +15 psig.

It is not always known during the design phase if a vacuum system will be backfilled in operation. However, operational experience at SNS and HFIR has shown that a vacuum system is almost always backfilled during venting. Therefore, it is a design best practice to always assume that a vacuum system will be backfilled, and design and analyze as a High Energy System, or control backfill flow and provide low pressure relief to ensure the system is Moderate Energy, under all credible operating and failure scenarios (for example a pressure regulator failure or a power failure during venting).

The pressure / vacuum system designer shall assume a margin of 10% for flow and pressure and 25° F for temperature or provide explanation within the DAC about why this is not a reasonable design assumption.

Low pressure and vacuum components are generally not required to be ASME Code certified or stamped. These components shall be fabricated in accordance with technical specifications selected by the design engineer. Components may be procured from commercial vendors with ASME Code certification whenever it may be expedient to do so.

Moderate Energy Systems shall include:

- An engineering analysis, showing that the system is safe
    - Each pressure system shall have a unique identifying number assigned
    - The analysis shall cite system's unique identifying number(s)
    - The analysis shall cite material specifications and properties matching material(s) specified on the drawings
        - Material properties should be the most conservative assumption taken from the ASTM Specification, when available, not from informal sources like MatWeb.
        - In the event a material is required but no ASTM standard exists, the material properties shall be determined using industry accepted product standards, or from mechanical properties determined by mechanical testing.
    - Heat treated materials that have been welded shall be analyzed in their non-heat treated state (for example, a part made from 6061-T6 that has been welded shall be analyzed as 6061-0) unless a post weld heat treatment is performed, in which case the appropriate material properties should match the new heat treated state.
        - Post heat treated parts must include a heat treatment report.
    - A static analysis must show a Factor of Safety of 2.0 or higher to material Yield Strength and 4.0 or higher to material Ultimate Strength is provided, or a fatigue analysis must be completed. Devices requiring a fatigue analysis must also include a conservative estimation of the component's cycle *rate.* The device shall be indelibly labeled, typically by etching, with an expiration date corresponding to its cycle life and cycle rate. If labeling is not practical due to the device's size, shape, or some other reason, then the device must be "bagged or tagged."

- A Test Report, performed to 110% or higher of Maximum Allowable Working Pressure (MAWP) for gases, or 130% or higher for liquids, including:
  - Citation of part number
  - Indication of test pressure
  - Description of test setup
  - If test is a destructive test, then material certifications for tested device shall also be provided
  - production device(s) must include material certifications, matching material specified on drawings and analysis.
- A Flow Diagram, System Schematic or P&ID clearly showing pressure relief devices, valves, piping, etc.

## 3.3 HIGH ENERGY SYSTEMS

High Energy Systems should be designed and analyzed per the most conservative applicable national and / or state consensus codes and applicable ORNL engineering standards. In cases where this is not possible or practical because the system is a vacuum system, material requirements, scientific use case, etc., Equivalent Protection Exhibit in SBMS may be followed. ORNL-1138 form or equivalent must be completed prior to operation.

### 3.3.1 Application of Equivalent Protection

10 CFR 851, Appendix A, Section 4 (c) imposes the following minimum requirements:

"When national consensus codes are not applicable (because of pressure range, vessel geometry, use of special materials, etc.), contractors must implement measures to provide equivalent protection and ensure a level of safety greater than or equal to the level of protection afforded by the ASME or applicable state or local code. Measures must include the following:

1. Design drawings, sketches, and calculations must be reviewed and approved by a qualified independent design professional (i.e., professional engineer). Documented organizational peer review is acceptable.
2. Qualified personnel must be used to perform examinations and inspections of materials, in-process fabrications, non-destructive tests, and acceptance test.
3. Documentation, traceability, and accountability must be maintained for each unique pressure vessel or system, including descriptions of design, pressure conditions, testing, inspection, operation, repair, and maintenance. "

Reference SBMS Exhibit: Equivalent Protection at
https://sbms.ornl.gov/sbms/SBMSearch/SubjArea/PresSys/ExhibitEquivalent.cfm

### 3.3.2 Design

#### 3.3.2.1 Structural Design

The Team Leader or Group Leader shall assign responsibility for component design to a qualified engineer to develop the design and prepare the required technical drawings, specifications, and the DAC. The Team Leader (or Group Leader) shall also assign another engineer having similar qualifications to conduct an independent review of the design.

The stress analysis for vacuum components shall demonstrate a positive margin against plastic collapse and buckling for loads imposed under all foreseeable operating, transient and upset conditions. Fatigue evaluations shall be performed for components subject to cyclic loadings.

The DAC prepared by the design engineer shall include a listing of the selected design parameters and the engineering evaluations applied to demonstrate conformance to the applicable design requirements. The DAC shall be reviewed and checked for completeness and accuracy by the independent design reviewer, who shall indicate approval by signing and dating the DAC. The approved drawings, DAC, and other technical documents shall be maintained in the design process control system used at the time of the calculation.

In lieu of full penetration welds, which may contain voids that could result in virtual leaks in vacuum components, the preferred technique for vacuum weld joints is to apply skip welds for structural strength on the exterior of the joint, with a continuous seal weld of minimal size on the inside of the joint. The structural analysis shall demonstrate such joint designs can withstand the anticipated loads.

When structural elements are subject to loads which are not primarily due to pressure, and pressure induced loads are not a controlling factor in their design thickness, consensus standards other than the ASME Boiler and Pressure Vessel Code may be the primary controlling factor in the component design.

#### 3.3.2.2 Allowable Stress Limits

The allowable stress values given in the tables of Section II, Part D of the ASME B&PV Code or the applicable ASME B31 Piping Code (as applicable) shall be observed whenever listed materials are selected by the design engineer.

When the design engineer selects a material which is not listed within these standards as acceptable for construction, the material properties shall be determined using industry accepted product standards, or from mechanical properties determined by mechanical testing. Allowable stress values shall be determined using these alternative methods shall follow the methodology given in ASME Section II, Part D, Appendices 1, 2, 3 or 10 (as applicable) to ensure suitable design margins have been applied. Where there is no safety risk, or approved safety mitigating measures are applied, higher design margins may be applied when determining appropriate stress values.

When it is necessary to use a material which is poorly documented or characterized for the component design to be able perform its intended scientific function, safety mitigation measures shall be applied to offset the potential safety risks to personnel. Safety mitigation measures may include using a secondary containment vessel, enclosure behind a protective barrier/wall, or establishing a personnel exclusion zone around the vessel or component when operating.

When a poorly characterized material must be used, the design review and approval process shall include a review and acceptance by engineering management, the responsible equipment operators, and independent safety reviewers.

#### 3.3.2.3 Welded or Brazed Fabrication

Welded or brazed fabrication shall comply with the requirements of SNS-QA- P051 and the applicable Standard of Qualification (SOQ) listed in the technical specifications. Welding procedure specifications (WPS) and welder performance qualifications (WPQ) shall be qualified in accordance with either ASME Section IX or American Welding Society (AWS) Standard B2.1. Brazing procedure specifications (BPS) and brazer performance qualifications (BPQ) shall be qualified in accordance with either ASME Section IX or American Welding Society (AWS) Standard B2.3. Procedure and performance qualification documents and performance continuity records shall be maintained as required by SNS-QA-P051 and the SOQ.

### 3.3.3 Inspection, Examination and Testing

#### 3.3.3.1 Visual Inspection

Vendor fabricated components shall be visually inspected to verify compliance with the procurement specification during their manufacture and upon completion by the STS quality representative or a designated third party, except for standard pressure parts whose pressure-temperature rating is provided in the parts manufacturer's literature, and which comply with an industry or manufacturer's standard. Visual inspections of completed weld joints shall be conducted by a certified weld inspector qualified under AWS QC-1, or by a Level II or III VT examiner qualified and certified by their employer’s written practice prepared in conformance with the applicable portions of ASNT SNT-TC-1A or CP-189. Inspections may be waived for welds on internal components which are inaccessible after assembly, or welds which are not pressure retaining. Inspections performed during the fabrication process shall include, but are not limited to verifying the following:

a) Condition and documentation of materials
b) Traceability of material identification to documentation
c) Weld joint fit-up, preparation, and welder identification markings on selected joints
d) Verification of critical dimensions within acceptable tolerances
e) Vessel cleanliness as specified for vacuum service (when applicable)

#### 3.3.3.2 Vacuum Test

All vacuum components shall be subjected to a vacuum test to verify their ability to withstand buckling loads. The vacuum test shall be performed at a maximum absolute internal pressure of $1x10^{-1}$ torr.

#### 3.3.3.3 Application of Nondestructive Examination (NDE)

Volumetric NDE methods such as radiography or ultrasonic examination may be specified by the design engineer to verify the integrity of weld joints, and to confirm the absence of voids and inclusions within welds. Volumetric NDE shall be performed using a written procedure which complies with the detailed technical requirements for the examination method which are provided in the applicable Article of ASME Section V. The written procedure shall be prepared and approved by a Level III examiner certified for conducting the applicable examination method. Examination procedures prepared in compliance with alternative standards may be accepted after used upon review and acceptance by the TPO prior to the examination. Personnel performing volumetric NDE shall be certified for the specific examination method per the requirements of their employer’s written practice prepared in conformance with the applicable portions of ASNT SNT-TC-1A or CP-189. The use of Liquid Penetrant surface NDE examinations on vacuum components is prohibited except where specifically required by the design engineer.

#### 3.3.4 Pressure Relief Devices

Reclosing or non-reclosing pressure relief devices (PRDs) used for overpressure protection shall be ASME certified whenever possible, bearing the ASME “V”, “UV”, or “UD” Code Symbol Stamp. The designer shall specify the set pressure and minimum relieving capacity required to ensure adequate overpressure protection. ASME certified PRDs may be installed without additional testing if the seals on the set pressure adjustments are intact. Burst disks shall be visually inspected prior to installation.

Vessels and components having internal, external or differential pressure ratings beyond the range of ASME certified PRDs may use PRDs which are not ASME certified, provided the PRD has been tested to verify its set point and relieving capacity. The PRD shall be made of materials suitable for the intended service. Alternatively, overpressure protection may be provided by system design.

#### 3.3.5 Records

As required by Federal regulations, records of safety reviews associated with a pressure or vacuum component shall be retained throughout their operating lifetime, and for 5 additional years following shut-down of the system. The design drawings (and/or “as built” drawings), sketches, calculations, reviews, tests, inspections, material certifications, qualification records, and fabrication records shall be maintained, along with pertinent operating history documents. For purposes of this requirement, inactive components in storage shall be considered “active” until they have been officially decommissioned and scrapped.

#### 3.3.6 Release For Use

The vessel shall not be released for use until all associated approved specifications, DACs, inspection documents, design reviews and drawings are released to the appropriate Document Control Center. The Engineer shall inspect the installation prior to commissioning.

## 4. REFERENCES

The following technical documents are referenced within the text of this document or provided technical guidance during its development. When referenced within this document, the referenced technical documents are mandatory only to the extent referenced, and the most recent revision or latest mandatory Edition and/or Addenda of the document shall be applied.


a. ASME Boiler and Pressure Vessel Code, Section VIII, “UnfiredPressure Vessels”

b. AWS QC-1, “Specification for Qualification and Certification of Welding Inspectors”

c. ASNT SNT-TC-1A, Recommended Practice Personnel Qualificationand Certification in Nondestructive Testing

d. ASNT CP-189, “ASNT Standard for Qualification and Certificationof Nondestructive Testing Personnel”

e. SNS-QA-P051, Rev.2, "Welding Program Description"

f. PNNL-18696, "Pressure Systems Stored-Energy Threshold Risk Analysis", SS Paulsen, August 2009