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Steam Pressure-Reducing Station Safety and Energy Efficiency Improvement Project

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Facilities and Operations Directorate

STEAM PRESSURE-REDUCING STATION SAFETY AND ENERGY EFFICIENCY IMPROVEMENT PROJECT

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ACRONYMS

ASME	American Society of Mechanical Engineers
CFR	Code of Federal Regulations
CPI	continuous process improvement
DOE	US Department of Energy
F&O	Facilities and Operations Directorate
FHRD	Fabrication, Hoisting, and Rigging Division
NPS	nominal pipe size
O&M	Operations & Maintenance
ORNL	Oak Ridge National Laboratory
PPE	personal protective equipment
SBMS	Standards-Based Management System
SPRS	steam pressure-reducing station

1. INTRODUCTION

The Facilities and Operations (F&O) Directorate is sponsoring a continuous process improvement (CPI) program.* Its purpose is to stimulate, promote, and sustain a culture of improvement throughout all levels of the organization. The CPI program ensures that a scientific and repeatable process exists for improving the delivery of F&O products and services in support of Oak Ridge National Laboratory (ORNL) Management Systems.

Strategic objectives of the CPI program include achieving excellence in laboratory operations in the areas of safety, health, and the environment. Identifying and promoting opportunities for achieving the following critical outcomes are important business goals of the CPI program:

- improved safety performance
- process focused on consumer needs
- modern and secure campus
- flexibility to respond to changing laboratory needs
- bench strength for the future
- elimination of legacy issues

The Steam Pressure-Reducing Station (SPRS) Safety and Energy Efficiency Improvement Project, which is under the CPI program, focuses on maintaining and upgrading SPRSs that are part of the ORNL steam distribution network. This steam pipe network transports steam produced at the ORNL steam plant to many buildings in the main campus site. The SPRS Safety and Energy Efficiency Improvement Project promotes excellence in laboratory operations by (1) improving personnel safety, (2) decreasing fuel consumption through improved steam system energy efficiency, and (3) achieving compliance with applicable worker health and safety requirements.

1.1 APPLICABLE REGULATIONS

Worker health and safety requirements that govern the conduct of contractor activities at US Department of Energy (DOE) sites are provided in 10 CFR 851, *Worker Safety and Health Program* (Ref. 1). This regulation establishes requirements for a worker safety and health program that reduces or prevents occupational injuries, illnesses, and accidental losses by providing DOE contractors and their workers with safe and healthful workplaces at DOE sites. The regulation also states that contractors must achieve compliance with all specific program requirements prescribed in 10 CFR 851, Subpart C.

According to 10 CFR 851, Subpart C—*Specific Program Requirements*, contractors must have a structured approach to their worker safety and health program which, at a minimum, includes provisions for pressure safety. In implementing the structured approach for pressure safety, contractors must establish safety policies and procedures to ensure that pressure systems are designed, fabricated, tested, inspected, maintained, repaired, and operated by trained and qualified personnel in accordance with applicable and sound engineering principles. In addition, contractors must ensure that all pressure vessels, boilers, air receivers, and supporting piping systems conform to (1) applicable American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (2004, Sections I through XII including Code Cases; (2) applicable ASME B31 (Code for Pressure Piping) standards; and (3) the strictest applicable state and local codes. 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

*Information about this program is presented at F&O web site http://portal.ornl.gov/sites/fo/cpip/default.aspx.

greater than or equal to the level of protection afforded by the ASME or applicable state or local codes.

The term “pressure system” includes all pressure vessels and pressure sources including cryogenics, pneumatic, hydraulic, and vacuum. Vacuum systems are considered pressure systems because of their potential for catastrophic failure posed by backfill pressurization. Associated hardware (e.g., gauges and regulators), fittings, piping, pumps, and pressure relief devices are also integral parts of the pressure system. This definition of pressure system, which is all encompassing and provides no exclusions, means that any leak tight pressure boundary is within the scope of DOE’s 10 CFR 851, *Worker Safety and Health Program*.

1.2 PERFORMANCE MEASURES

The SPRS Safety and Energy Efficiency Improvement Project is aligned with F&O CPI program strategic objectives and achieves many of the F&O critical outcomes. The following tangible and intangible results represent performance measures for characterizing project success:

- boiler fuel and related energy cost savings
- reduced air emissions (primarily carbon monoxide, carbon dioxide, and oxides of nitrogen)
- increased productivity
- positive impact on customer satisfaction
- positive impact on quality of services
- improved work environment
- enhanced environmental, safety, and health compliance
- enhanced capabilities, expertise, and knowledge

2. STEAM SYSTEM DESCRIPTION

Steam is used at ORNL for a variety of process heating applications including space heating and conditioning. The steam is produced by a fuel-fired boiler at the ORNL steam plant and distributed throughout the main campus by a complex steam-pipe network. At any given time, the amount of steam produced by the steam plant is primarily a function of building steam demand and thermal energy losses from the steam-pipe network. Because fuel is the dominant cost in steam generation (Ref. 2), reducing boiler fuel consumption by improving the energy efficiency of the steam system is key to lowering ORNL’s overall utility cost. Reducing fuel consumption also decreases air emissions, including carbon monoxide, carbon dioxide, particulate matter, and oxides of nitrogen.

The steam-pipe network distributes steam throughout the main ORNL campus at a maximum temperature of 275°F and a maximum pressure of 250 psig. An SPRS located at each building reduces the steam supply pressure to the pressure required to operate space heating and conditioning equipment and other steam devices, typically 30 psig or less. To accomplish this objective, these stations include a variety of mechanical components such as isolation and control valves, steam traps, strainers, distribution piping and related fittings, pressure relief devices, and condensate return lines. Thermal insulation is installed on the outside surfaces of most steam lines to reduce heat loss.

The overall configuration of an SPRS depends on a variety of factors such as physical space limitations, steam flow requirements, pipe and valve sizes, methods of steam flow control, and the number of connections required to distribute the steam to the end-use equipment. Some SPRSs are located inside the building while others are located outdoors. Although there is no standard configuration, each station is required to perform the following functions:

- receive steam from the steam plant
- reduce steam pressure
- control steam flow into the building
- collect condensate and either discharge it to the atmosphere or return it to the boiler

An example of a newly constructed SPRS is shown in Fig. 1.

Fig. 1. Newly constructed steam pressure-reducing station.

Although steam is an effective energy-transfer medium, there are potential safety hazards associated with its distribution and use. These hazards include effects of uncontrolled steam releases and exposure to heated surfaces. At ORNL, these hazards are controlled by constructing and maintaining a leak tight steam confinement boundary and limiting access and exposure to heated surfaces by installing and using physical barriers such as heat shields, thermal insulation, and personal protective equipment (PPE). Avoiding uncontrolled steam releases and installing thermal insulation on heated surfaces also helps ORNL reduce boiler fuel consumption by increasing the thermal efficiency of the steam system.

3. SAFETY AND ENERGY EFFICIENCY IMPROVEMENT PROJECT DESCRIPTION

The SPRS Safety and Energy Efficiency Improvement Project is being performed by F&O with the following key objectives:

- Comply with the DOE's worker health and safety program requirements for pressure safety by constructing and maintaining a leak tight steam confinement boundary.

- Decrease energy consumption and lower utility operating costs by eliminating steam leaks and reducing thermal energy losses.

Justification for the project is based on results of routine field inspections of steam traps and pressure relief devices conducted in 2006. These inspections were performed in accordance with ORNL Standards-Based Management System (SBMS) annual inspection requirements to supplement previous inspection activities performed by a subcontractor. Table 1 summarizes key safety and compliance issues and describes opportunities for saving energy that were identified by the inspection teams during this limited scope field effort.

Table 1. Steam trap and pressure relief device inspection findings

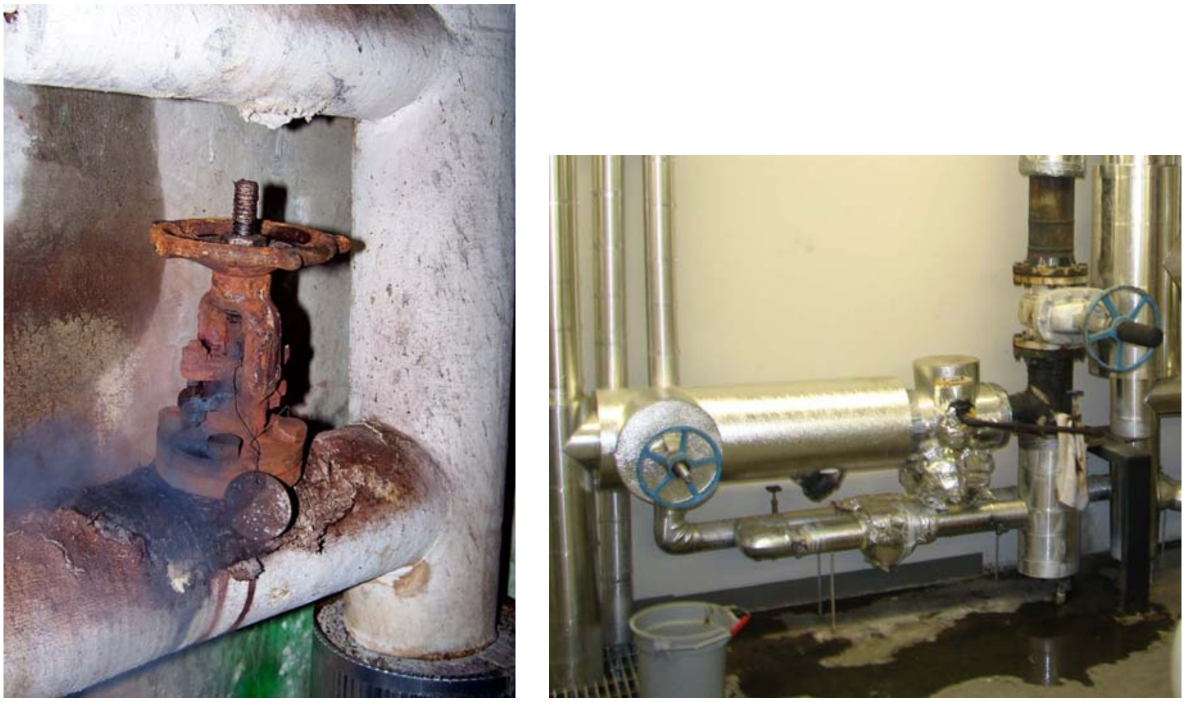
Inspection finding	Safety and compliance issue	Energy savings opportunities
Missing, damaged, or defective steam traps	Burn and scald hazards Water hammer effects	Increase steam system energy efficiency by controlling condensate releases and eliminating uncontrolled steam releases
Improperly sized, incorrectly applied, or failed steam traps	Burn and scald hazards Water hammer effects	Increase steam system energy efficiency by controlling condensate releases, reducing the water content of steam, and eliminating uncontrolled steam releases
Damaged, leaking, defective, plugged, or undersized pressure relief devices	Burn and scald hazards Effects of uncontrolled steam releases caused by excessive system pressure or use of deficient pressure retaining components that do not comply with requirements in applicable codes and standards	Increase steam system energy efficiency by eliminating uncontrolled steam releases
Deficient inspection records for pressure relief devices (no records located for about 150 devices)	Noncompliance with Standards-Based Management System and DOE requirements for inspection of pressure relief devices	Not applicable
Deficient steam piping design and construction	Burn and scald hazards Water hammer effects resulting from improper operating procedures, failure of pressure retaining components, or use of deficient pressure retaining components that do not comply with requirements in applicable codes and standards	Increase steam system energy efficiency by eliminating uncontrolled steam releases
Damaged, degraded, leaking, or defective valves, fittings, piping, strainers, and other pressure components	Burn and scald hazards Shrapnel hazards resulting from failure of pressure retaining components or use of deficient pressure retaining components that do not comply with requirements in applicable codes and standards	Increase steam system energy efficiency by eliminating uncontrolled steam releases
Missing or inadequate thermal insulation	Burn hazard	Increase steam system energy efficiency by reducing heat loss
Improper material type or grade	Burn and scald hazards Shrapnel hazards resulting from failure of pressure retaining components or use of deficient pressure retaining components that do not comply with applicable codes and standards	Not applicable

Examples of damaged and deficient steam piping and SPRS components found during the field inspections are shown in Figs. 2 and 3.

3.1 SAFETY ISSUES

Human burn injuries can occur when the outer layer of skin cells contact a heated surface such as an uninsulated steam line. The degree of the burn (i.e., first, second, or third degree) is a function of many factors, including the temperature of the heated surface and the period of contact exposure. For a given degree of burn injury, the period of contact exposure decreases as the heated surface temperature increases, but this relationship is not linear (Ref. 3). Burn injuries can also occur when the skin is exposed to hot water or steam. The key to avoiding human burn injury is to prevent skin cells from contacting a heated surface for an extended period, avoid immersing skin cells in hot water, and protect skin cells from steam impingement. Use of physical barriers such as thermal insulation, heat shields, and PPE are effective methods for mitigating burn hazards. Training is also required to educate workers about burn hazards and effective methods for preventing burn injuries. Injuries resulting from steam system shrapnel can occur when a pressurized component fails and produces missiles. Root causes for failures that produce missiles include, but are not limited to, metal loss due to corrosion or erosion, fracture resulting from a state of overstress, crack propagation, system overpressure events, and water hammer phenomena. Preventing shrapnel injuries requires implementing a comprehensive mechanical integrity management program that addresses the root causes for pressurized component degradation or failure. Such programs include measures for properly sizing, selecting, installing, inspecting, repairing, and replacing pressure relief devices as delineated in the ASME Boiler and Pressure Vessel and Piping Codes and ORNL specifications.

Fig. 2. Leaking steam piping and deficient piping support.



(a) **(b)**

Fig. 3. Degraded steam isolation valve and missing thermal insulation (a) and corroded piping and leaking valves (b).

3.2 ENERGY EFFICIENCY ISSUES

Energy savings opportunities identified during the 2006 inspections are consistent with those for most industrial steam systems where energy surveys typically reveal that reducing steam leaks is a significant area of potential energy savings (Ref. 4). Steam trap failures generally account for a large portion of the leaks, but steam leaks from defective piping components are also a major source of wasted energy. Uninsulated steam lines are another important source of wasted energy, especially when the steam line surface temperature exceeds 120°F.

The following recommendations reflect DOE experience with industrial steam system surveys and are equally applicable to the ORNL steam system:

- Find and repair steam leaks.
- Evaluate insulation condition (Refs. 5 and 6).
- Implement a steam trap management program (Ref. 7).
- Investigate potential areas for condensate return (Ref. 8).

3.3 ACTIONS TAKEN TO ADDRESS SAFETY AND ENERGY EFFICIENCY ISSUES

Actions taken as part of the SPRS Safety and Energy Efficiency Improvement Project to address safety and energy efficiency issues identified during the 2006 inspections include the following:

- issuing ORNL Engineering Standard, *Steam and Condensate Heating Piping*, UT-Battelle 232213, 2006
- updating ORNL Engineering Standard, *Steam and Condensate Heating Piping*, UT-Battelle 232213, Rev. 1, 2008

- updating ORNL Engineering Standard, *General Duty Ball Valves for Steam Piping,* UT-Battelle 15099, 2006
- participating in pressure relief device sizing and inspection training
- repairing or replacing more than 40 defective pressure relief devices using a certified valve shop
- conducting hazard assessments to identify health and safety hazards to workers and implementing hazard prevention and abatement measures
- identifying applicable codes and standards, implementing measures to provide equivalent protection, and ensuring a level of safety greater than or equal to the level of protection afforded by the ASME or applicable state and local codes
- participating in steam trap sizing and installation training
- verifying pressure relief valve sizing
- replacing defective steam traps with the proper type and size
- replacing damaged or degraded pressure retaining components to eliminate steam leaks and potential consequences of shrapnel
- providing configuration improvements to facilitate future maintenance, repair, and inspection activities
- realigning and reconfiguring piping to avoid water traps and potential steam expansion and water hammer events that could result in failure of a pressure retaining item including, but not limited to, shrapnel
- installing and replacing missing or damaged thermal insulation
- providing steam flow path redundancy and installing additional isolation valves to improve steam system reliability, safety, operability, inspectability, and maintainability
- compiling technical information about the SPRS design, construction, as-found condition, and as-repaired condition to update drawings and compliance documents
- conducting awareness training about health and safety hazards
- installing isolation valves to provide redundancy in accordance with lockout-tagout procedures
- installing bypass lines to improve safety and efficiency during start-up and shutdown operations and maintenance, repair, and inspection activities

Following the initial inspections in 2006, project activities continued with additional SPRS inspections and follow-up modification, repair, and replacement activities. To support these activities, the ORNL pipe shop (shown in Fig. 4) was upgraded and equipped to provide a suitable and safe work space.

Fig. 4. Refurbished Oak Ridge National Laboratory pipe shop.

4. SAFETY IMPROVEMENTS

Worker safety and health regulations adopted by DOE for pressure safety are defined in 10 CFR 851 (Ref. 1). These regulations apply to all pressure systems at ORNL including the SPRSs. According to definitions in 10 CFR 851.3, “pressure systems” include all pressure vessels and pressure sources including cryogenics, pneumatic, hydraulic, and vacuum. Associated hardware (e.g., gauges and regulators), fittings, piping, pumps, and pressure relief devices are also integral parts of the pressure system. Standards that apply specifically to the ORNL steam system including SPRSs are identified in 10 CFR 851.27. They include the following codes issued by ASME:

- ASME *Boilers and Pressure Vessel Code,* Sections I, IV, V, VIII, and IX, including applicable Code Cases
- ASME Code for Pressure Piping, B31.1—2001—*Power Piping* and B31.1a—2002, Addenda to ASME B31.1, 2001
- ASME Code for Pressure Piping, B31.3—2002—*Process Piping*

Complying with pressure safety regulations in 10 CFR 851 requires establishment of safety policies and procedures for ensuring that pressure systems are designed, fabricated, tested, inspected, maintained, repaired, and operated by trained and qualified personnel in accordance with applicable and sound engineering principles. In the SPRS Safety and Energy Efficiency Improvement Project, achieving compliance with 10 CFR 851 requirements began with collecting pressure system information about the design and construction of each SPRS and then using that information to identify and assess the hazards. The primary objective of a SPRS hazard assessment is to develop control measures for preventing or abating identified hazards. Other important compliance elements of the SPRS Safety and Energy Efficiency Improvement Project involved mechanical integrity management and worker training.

4.1 PRESSURE SYSTEM INFORMATION

Accurate, complete, written pressure system information is essential to an effective hazard assessment as required by 10 CFR 851.21. In the SPRS Safety and Energy Efficiency Improvement Project, both process information and mechanical design data were collected including descriptions of the SPRSs and documentation necessary to establish their design bases. The following types of design basis information were collected:

- applicable codes and standards
- block flow diagrams and piping and instrumentation diagrams
- design drawings and engineering calculations
- fabrication and assembly drawings
- material and component specifications, reports, and information including documents supplied by the material and component manufacturers
- welding procedures and specifications
- weld maps
- nondestructive examination methods, procedures, and inspection techniques
- operating procedures
- hazard assessments and hazard mitigation plans

Codes and standards used to establish good engineering practice were also identified and compared to the list of applicable codes and standards in 10 CFR 851, Appendix A, Section 4.

Although pressure system information may exist in many forms, reference to important documents is provided whenever items are not readily available. Without complete pressure system information, it can be difficult or impossible to perform an effective hazard assessment or determine whether process changes or SPRS equipment modifications increase the risk of an uncontrolled release. Establishing and maintaining complete and accurate pressure system information is a record-keeping requirement defined in 10 CFR 851.26.

Activities involved in collecting pressure system safety information for the SPRS Safety and Energy Efficiency Improvement Project are described in Table 2. Table 3 shows the categories used to organize the pressure system information and the types of information included in each category.

Because the original technical information for a SPRS frequently was not available or no longer existed, the pressure system safety information was developed in sufficient detail to support a hazard assessment and to comply with record-keeping requirements.

4.2 PRESSURE SYSTEM HAZARD ASSESSMENT

A pressure system hazard assessment is an organized and systematic effort to identify, evaluate, and control the hazards involved in maintaining a gas or liquid within a leak tight pressure system consisting of different interconnected pressure retaining components. The objective of a pressure system hazard assessment is to determine areas of excessive risk where preventative and mitigative measures may be warranted to better control the hazards. A hazard assessment also helps identify accident scenarios that could lead to worker injuries or fatalities, property damage, public exposure to chemicals, environmental impacts, or other adverse consequences.

Table 2. Procedure for collecting pressure system information for the SPRS Safety and Energy Efficiency Improvement Project

Step	Activity
1	Identify the SPRS using appropriate terms and alphanumeric characters that adequately distinguish this SPRS from others at ORNL. Include the owner of the SPRS and the name of the Facility Engineer or Complex Facility Manager responsible for the space where the SPRS is located as part of the pressure system information
2	Establish the performance requirements and operating conditions for the SPRS in sufficient detail to allow an assessment of the potential hazards associated with operating and maintaining the SPRS
3	Define the physical boundaries and functional interfaces for the SPRS so that the overall location and interconnections with other systems or processes are clearly identified
4	Characterize the nature of the hazards associated with the SPRS during normal operating conditions and all postulated abnormal events including emergency shutdown scenarios. Address this information in the hazard assessment
5	Gather information pertaining to the technology of the SPRS and the equipment in the SPRS
6	Document the design basis for the SPRS using the compiled pressure system information

Results of a pressure system hazard assessment can provide managers and workers with information needed to improve safety and reduce the consequences of unwanted or unplanned releases from a pressure system. A hazard assessment based on complete and accurate pressure system information is the cornerstone of effective pressure system safety management.

Table 3. Pressure system information categories

Pressure system hazards and technology
Maximum and minimum acceptable temperature, pressure, and flow conditions
Mechanical design criteria including performance requirements for the pressure relief devices and associated venting path that protect the SPRS from overpressure during the postulated worst credible release scenario
Instrumentation and control design criteria including safety limits and shutdown equipment
Process design documentation including analytical details, test results, and energy balance data
Start-up, normal, shutdown, and emergency operating procedures
Operator qualifications, training requirements, and requalification frequency
Pressure system equipment
Block flow diagrams, simplified process flow drawings, piping and instrumentation diagrams, photographs, and instrumentation and control drawings including information about the pressure relief system and its design basis
Structural and mechanical construction drawings for the SPRS and related facilities
Applicable design and construction codes for each pressure retaining item in the SPRS
Construction material specifications, fabrication and inspection procedures, inspection and test results, weld maps, and quality assurance records
Pressure vessel construction drawings issued by the manufacturer and the identification number for each pressure vessel in the process including copies of all National Board of Boiler and Pressure Vessel Inspectors registration documents, if applicable
Procurement specifications and quality assurance documentation for items such as piping, valves, fittings, and sensors that are part of the SPRS including the pressure relief systems
Manufacturer's data and identification numbers for pressure relief devices including the set pressures and measured relieving capacities
User manuals, schematics, drawings, and related documentation for safety and control systems including descriptions of safety equipment used in process control, emergency shutdown, and interlock systems

Analyzing designs of new pressure systems and modifications to existing pressure systems and their pressure retaining components for potential workplace hazards is required by 10 CFR 851.21. Such assessments must be performed initially to obtain baseline information and as often thereafter as necessary to ensure compliance with the requirements in 10 CFR 851, Subpart C. Consideration of the pressure system information is an essential part of an effective hazard assessment.

The hazard assessments conducted as part of the SPRS Safety and Energy Efficiency Improvement Project were performed by a team of experienced individuals with varied operational and technical backgrounds. At least one team member was familiar with the physical features and performance requirements for the SPRS. The team leader was knowledgeable about the applicable standards, codes, specifications, and regulations.

Team efforts focused on establishing controls for all identified and potential SPRS safety hazards so the controls could be incorporated in the facility design or operating procedures. Hazard controls were selected based on the following hierarchy, which is defined in 10 CFR 851.22.

1. Elimination of the hazards where feasible and appropriate
2. Engineering controls where feasible and appropriate
3. Work practices and administrative controls that limit worker exposures
4. PPE

The hazard assessment for each SPRS was documented and recorded as required by 10 CFR 851.26 and included as part of the pressure system information. Any modifications or updates to the hazard assessment will be documented to keep the hazard assessment current. Table 4 shows the hazard assessment procedure used to identify hazards and develop control measures for eliminating or abating hazards.

Table 4. Hazard assessment procedure used in the SPRS Safety and Energy Efficiency Improvement Project

Step	Activity
1	Conduct a hazard assessment using one or more of the following methodologies that are appropriate to determine and evaluate the hazards of the SPRS being analyzed: • What-If • Checklist • Hazard and Operability Study • An appropriate equivalent methodology The hazard assessment should address the following: • process hazards • identification of any previous incident with a likely potential for catastrophic consequences in the workplace • engineering and administrative controls applicable to the hazards and their interrelationships • consequences of failure of engineering and administrative controls • facility siting • human factors • evaluation of a range of possible safety and health effects on employees in the workplace as a result of a control failure
2	Characterize the applicable engineering and administrative controls applicable to the SPRS. Acceptable detection methods might include process monitoring and control instrumentation with detection hardware such as sensors. The adequacy of the pressure relief devices and the pressure relief vent path for controlling excessive pressure accumulation was also assessed
3	Define the consequences of failure of the engineering and administrative controls: • Possible consequences of failure of a pressure retaining item resulting from overpressure include shrapnel (missiles) and thermal (burns and scalding) effects • Possible causes for overpressure include ✓ excess material inflow or outflow ✓ thermal expansion of the confined material ✓ vaporization due to heat input from external sources such as a fire
4	Provide information for updating the initial hazard assessment whenever the SPRS design or equipment is modified, process technology changes alter the design basis, or operating procedures are revised. As a minimum, the hazard assessment should be periodically updated at prescribed intervals
5	Document the initial and subsequent hazard assessments. Documentation, traceability, and accountability must be maintained for each SPRS in accordance with applicable SBMS procedures and DOE requirements. Each hazard assessment should be included as part of its pressure system information and reflected in its operating and maintenance procedures

Information categories in Table 5 were considered by the hazard assessment team when identifying potential hazards, establishing controls, and assessing failure consequences.

Table 5. Information considered by the SPRS hazard assessment team

SPRS and process technology
Construction of new facilities, modifications to existing facilities, installation of new or additional components, or removal of equipment included in the initial design
Significant changes in operating conditions such as an increase in pressure, temperature, or flow rate, or variations in other process conditions from those represented in the design basis
Changes in start-up, normal operating, or shutdown procedures
SPRS equipment
Replacement of existing equipment with similar but not original or equal equipment
Installation of bypass connections or interconnections between pressure retaining items not included in the initial design
Use of temporary piping, connections, hoses, or utility services
Modifications to equipment operating procedures
Alterations or repairs particularly those made without approved procedures or authorized in-service inspections

Potential hazards identified by the assessment team were attributed to one or more of the following common types of problems identified by the inspectors:

- damaged, degraded, or improperly sized pressure retaining components
- incorrect piping configurations
- leaky components including failed steam traps and defective pressure relief devices
- missing thermal insulation
- prohibited materials and components

SPRS inspection findings revealed opportunities for reducing the risk of injury to workers. Common control measures for eliminating and abating hazards included the following:

- reconfiguring SPRSs to facilitate operations and provide safe and convenient access for maintenance, repair, and inspection
- replacing corroded, damaged, degraded, or inoperable pressure retaining components including steam traps, control valves, isolation valves, pressure relief devices, gaskets, temperature sensors, pressure gauges, etc.
- installing and repairing structural supports and pipe hangers
- installing approved pressure relief devices of the proper size and type
- modifying the pressure relief path to eliminate flow blockage or restriction
- realigning the pressure relief path to direct releases to a safe location or area
- installing thermal insulation
- identifying and marking pressure retaining components
- using appropriate PPE

4.3 MECHANICAL INTEGRITY MANAGEMENT

Structural capacity and leak tight integrity of pressure retaining components in a SPRS can be adversely affected by factors such as the performance history, operating conditions, service environment, and physical damage.

Although effects of these factors on safety can vary significantly from one station to another, the mechanical integrity management approach used to evaluate fitness-for-service considered these factors on a case-by-case basis. The steps in Table 6 and the applicable guidance and requirements in the documents listed in Table 7 were considered in developing a management approach for ensuring SPRS mechanical integrity.

Table 6. Mechanical integrity management considerations for the SPRS Safety and Energy Efficiency Improvement Project

Step	Consideration
1	Verify that the pressure system information is accurate and complete including information about performance history, operating conditions, and service environment and that the hazard assessment is current
2	Review written maintenance procedures for each pressure retaining item in the SPRS. Each procedure identifies the pressure retaining items to which the procedure applies and prescribes the type and frequency of required maintenance. Individualized maintenance procedures are not needed for identical or very similar pressure retaining items in similar service
3	Train maintenance personnel
4	Perform maintenance at prescribed intervals
5	Develop written in-service inspection and test procedures. The producers should specify the inspection and test methods, frequency, and evaluation requirements. Acceptance and rejection criteria for fitness for continued service should also be defined in the procedures
6	Conduct in-service inspections and tests at prescribed intervals
7	Remove, repair, or replace pressure retaining items that do not meet acceptance criteria for continued service
8	Document maintenance, repair, and replacement activities; record in-service inspection and test results; update SPRS information; and maintain records

Table 7. Documents considered in managing mechanical integrity for the SPRS Safety and Energy Efficiency Improvement Project

Pressure system information
Design description documentation
SPRS hazard assessments
Start-up, normal, shutdown, and emergency operating procedures and operating conditions
Maintenance manuals and manufacturer-supplied documents
Block flow diagrams, simplified process flow drawings, piping and instrumentation diagrams, instrumentation and control drawings, and construction drawings for the SPRS and its pressure retaining items
Procurement specifications and quality assurance documentation for spare and replacement parts and materials
Manufacturer’s data and identification numbers for pressure relief devices including the set pressures and measured relieving capacities
Construction material specifications, fabrication and inspection procedures, inspection and test results, and quality assurance records
Previous maintenance and repair documentation
Mechanical design criteria including performance requirements for the pressure relief devices and associated venting paths that protect the SPRS from overpressure during the postulated worst credible release scenario
Safety and control systems including descriptions of safety equipment used in process control, emergency shutdown, interlock, alarm, detection, or suppression systems

Table 7. (continued)

National consensus codes and standards (applicable edition)
ASME Boiler and Pressure Vessel Code, Sections I, IV, V, VIII, and IX , as applicable[a]
ASME B31.1—*Power Piping*[a]
ASME B31.3—*Process Piping*[a]
National Board Inspection Code[b]
International Building Code[c]
International Fire Code[c]

[a]Published by the American Society of Mechanical Engineers (ASME).
[b]Published by the National Board of Boiler and Pressure Vessel Inspectors.
[c]Published by the International Code Council.

4.4 WORKER TRAINING

Training and information requirements for DOE's Worker Safety and Health Program are defined in 10 CFR 851.25. For pressure systems, compliance with these requirements involves developing and implementing a worker safety and health training and information program for ensuring that all workers who are exposed or potentially exposed to pressure system hazards are provided with training and information on those hazards in order to perform their duties in a safe manner. The training and information program applies to both ORNL employees and subcontractors who may be exposed to pressure system hazards or affected by a pressure system release as specified in 10 CFR 851.25(a) and (c). Pressure-system safety training is also required to comply with management responsibilities defined in 10 CFR 851.20(a)(5) for providing workers with access to relevant program information. Examples of ORNL safety training specific to SPRS renovation activities are listed in Table 8.

All workers including maintenance employees, laboratory personnel, subcontractors, and other support staff involved with a particular pressure system need to fully understand its safety and health hazards. An effective training and information program specific to pressure system safety includes initial training, periodic refresher training, and additional training when new or increased hazards are introduced into the workplace. Each type of training needs to emphasize the specific safety and health hazards, emergency operations including shutdown, and safe work practices applicable to the employee's job tasks involving a particular pressure system. Records generated as part of pressure system training should be prepared and properly stored to comply with training and information requirements in 10 CFR 851.25 and 10 CFR 851.26. Table 9 lists the training activities being implemented as part of the SPRS Safety and Energy Efficiency Improvement Project.

Table 8. Examples of ORNL safety training specific to SPRS renovation activities

Identifier	Training description
50044993	Fire Watch
50046009	ORNL General Respirator
50046789	Ladder Safety
50046953	ORNL Confined Space
50047112	Hearing Conservation
50116610	General Hazard Communication
50117906	Walking/Working Surfaces and Fall Protection
50121788	Asbestos Operations and Maintenance (O&M) Initial
50121789	Asbestos O&M Refresher

Table 8. (continued)

Identifier	Training description
50121790	Asbestos Supervisor Initial
50121791	Asbestos Supervisor Refresher
50148731	Erecting/Dismantling Scaffolding Safely
50152324	Using Scaffolding Safely/Performance of Work
50152621	Hot Work
50181510	Condensate Inducted Water Hammer
50198762	Lockout-Tagout
50209214	Suspect/Counterfeit Items Overview
50229012	Incidental Hoisting and Rigging
50322773	Condensate Inducted Water Hammer Refresher

Table 9. Training activities, requirements, and completion status for the SPRS Safety and Energy Efficiency Improvement Project

Step	Activity
1	Provide initial SPRS safety training to new workers before or at the time of initial assignment to a job involving exposure to a SPRS hazard, as required by 10 CFR 851.25(b)(1). This training includes an overview of the SPRS information, hazards, and hazard control applicable to the particular SPRS at the job site. Depending on the SPRS design, additional training in subjects such as operating procedures and safety work practices, emergency evacuation and response, safety procedures, routine and nonroutine work authorization activities, and other areas pertinent to SPRS safety and health is covered as part of initial training
2	Conduct refresher training, if necessary, for each worker involved in operating a SPRS to ensure that the worker understands and adheres to the current operating procedures. The appropriate frequency of refresher training is based on consideration of changes to the SPRS information or hazard assessment and consultation with the workers who are exposed to the potential hazards of the SPRS
3	Conduct additional training whenever new or increased SPRS hazards are indicated based on changes to the pressure system information or revisions to the hazard assessment as required by 10 CFR 851.25(b)(2) and 10 CFR 851.25(b)(3)
4	Prepare and store records generated as part of SPRS training in accordance with10 CFR 851.25 and 851.26 requirements

4.4.1 General SPRS Safety Training

General SPRS training provides workers with an overview of the health and safety issues associated with building, operating, testing, maintaining, altering, and repairing SPRSs. This training focuses on awareness of the types of pressure retaining components that may be part of a SPRS, potential hazards to the human and natural environment associated with the stored energy, and possible consequences of an uncontrolled or unplanned release.

4.4.2 Customized SPRS Safety Training

Customized SPRS safety training provides workers with the pressure system information, hazard assessment results, and hazard controls specific to the particular SPRS. Periodic or additional training is generally required when changes to the SPRS introduce new hazards or increase existing hazards. Depending on the SPRS design, additional training may be necessary in subjects such as operating procedures, safety work practices, emergency evacuation and response, and safety procedures.

4.4.3 Training Records

SPRS training records that identify the trainee, date of training, and method used to verify successful completion and understanding of the training are maintained as part of the pressure system safety information and stored in SAP in accordance with SBMS procedures.

5. ENERGY SAVINGS IMPROVEMENTS

The SPRS inspections conducted in 2006 also revealed opportunities for ORNL to save energy by eliminating unwanted steam releases and decreasing heat losses from the steam-pipe network. Making these SPRS improvements achieves the following energy and cost savings objectives:

- Decrease boiler fuel consumption by reducing steam demand.
- Reduce utility operating costs.
- Avoid air emissions by decreasing boiler fuel consumption.

5.1 THERMAL INSULATION

Uninsulated steam distribution and condensate return lines are a potential source of heat loss that represents wasted energy (Ref. 5). Table 10 shows estimated heat losses from various sizes of uninsulated steam distribution lines. Installing insulation on these lines can reduce energy losses by up to 90%. From an energy savings viewpoint, any surface over 120°F should be insulated including steam and condensate return piping, valves, and fittings. Besides saving energy, maintaining surface temperatures of steam lines and related equipment at or below 120°F will reduce the potential for burn injuries and help mitigate the burn hazard.

Table 10. Estimated heat losses from uninsulated steam lines[a]

Distribution line diameter (in.)	Heat loss per 100 ft of uninsulated steam line (MMBtu/yr)[b]		
	Steam pressure (psig)		
	15	150	250
1	140	285	345
2	235	480	580
4	415	850	1,030
8	740	1,540	1,867
12	1,055	2,200	2,673

[a]Based on horizontal steel pipe, 75°F ambient air, no wind, and 8,670 operating hours per year, using methodology presented in *Insulate Steam Distribution and Condensate Return Lines,* US Department of Energy, DOE/GO-102006-2249, Steam Tip Sheet 2, January 2006.
[b]MMBtu equals 1 million British thermal units and is the customary unit adopted by DOE for reporting annual heat-loss data.

Although the unit cost of boiler fuel varies over time, the energy savings realized by installing thermal insulation on uninsulated steam lines can be significant as illustrated in Table 11.

Table 11. Estimated annual fuel cost savings realized by installing thermal insulation on 100 ft of uninsulated steam lines[a]

Distribution line diameter (in.)	Steam pressure (psig)	Estimated heat loss (MMBtu/year/100 ft)	Estimated annual fuel cost savings ($)
1	15	140	1,200
	250	345	2,957
4	15	415	3,557
	250	1,030	8,829
8	15	740	6,343
	250	1,867	16,003
12	15	1,055	9,043
	250	2,673	22,911

[a]Based on horizontal steel pipe, 75°F ambient air, no wind, 8,670 operating hours per year, boiler efficiency of 84%, thermal insulation efficiency of 90%, and unit cost for boiler fuel of $8.00/MMBtu, using methodology presented in *Insulate Steam Distribution and Condensate Return Lines*, US Department of Energy, DOE/GO-102006-2249, Steam Tip Sheet 2, January 2006.

Energy savings can also be realized by installing removable thermal insulation on valves and fittings (Ref. 6). Table 12 shows the estimated heat loss and potential fuel cost savings from installing removable insulated valve covers on various sizes of valves.

Table 12. Estimated annual fuel cost savings realized by installing removable insulated valve covers[a]

Valve size (in.)	Operating temperature (°F)	Estimated heat loss (Btu/h)	Estimated annual fuel cost savings ($)
3	250	1,255	105
4	250	1,695	141
8	250	3,500	292
12	250	5,250	438

[a]Based on installation of a 1 in. thick insulating pad on an ANSI 150-lb-class flanged valve in 75°F ambient air, no wind, 8,670 operating hours per year, boiler efficiency of 84%, and unit cost for boiler fuel of $8.00/MMBtu, using methodology presented in *Install Removable Insulation on Valves and Fittings*, US Department of Energy, DOE/GO-102006-2262, Steam Tip Sheet 17, January 2006.

5.2 UNCONTROLLED STEAM RELEASES

The following sources of uncontrolled steam releases were identified during the 2006 inspections:

- failed steam traps
- defective pressure relief devices
- leaking valves, flanges, and fittings

The steam loss potential from each of these sources is a function of the steam pressure and the size of the discharge opening (Ref. 7). Estimated discharge rates and associated fuel cost savings from various sizes of failed steam traps are shown in Table 13. Annual fuel cost savings for eliminating similar size leaks in pressure relief devices, valves, flanges, and fittings are comparable. Steam trap testing intervals recommended by DOE (Ref. 7) are shown in Table 14.

Table 13. Estimated annual fuel cost savings realized by repairing or replacing failed steam traps[a]

Orifice diameter (in.)	Steam pressure (psig)	Estimated steam loss (lb/h)	Estimated annual fuel cost savings ($)
1/16	15	3.4	322
	250	30.4	2,882
1/8	15	13.7	1,297
	250	122	11,547
1/4	15	54.7	5,180
	250	487	46,117
3/8	15	123	11,648
	250	1,096	103,786

[a]Based on 8,670 operating hours per year and unit cost of $10.81 per 1,000 lb of steam, which corresponds to a boiler efficiency of 84% and an $8.00/MMBtu unit cost for boiler fuel, using methodology presented in I*nspect and Repair Steam Traps*, US Department of Energy, DOE/GO-102006-2248, Steam Tip Sheet 1, January 2006.

Table 14. Recommended steam-trap testing intervals[a]

Steam pressure	Steam-trap test interval
High pressure (150 psig and above)	Weekly to monthly
Medium pressure (30 to 150 psig)	Monthly to quarterly
Low pressure (below 30 psig)	Annually

[a]Source: *Inspect and Repair Steam Traps*, US Department of Energy, DOE/GO-102006-2248, Steam Tip Sheet 1, January 2006.

6. PAYBACK ANALYSIS

The annual fuel cost savings realized by repairing or replacing leaky SPRS components and installing thermal insulation on uninsulated steam pipes can be significant. Economic justification for taking these actions can be based on results of a simple payback analysis, which involves the following steps:

- quantify the annual energy savings potential
- develop a repair-maintenance plan including system modifications, if necessary
- estimate the cost for implementing the repair-maintenance plan
- determine the payback in years by dividing the implementation cost by the annual fuel cost savings

Because payback periods are inversely proportional to boiler fuel cost, steam system repair and maintenance activities become more cost effective as the cost of boiler fuel increases. Payback periods are also useful in prioritizing SPRS repair and maintenance activities based on cost.

7. CASE STUDIES

The ORNL steam-pipe network includes more than 150 SPRSs. These stations are categorized by the nominal pipe size (NPS) of the steam piping as follows:

- small stations with piping up to and including NPS 3
- medium stations with piping between NPS 4 and NPS 6
- large stations with piping equal to or greater than NPS 8

Each of these pipe networks confine steam, which is a compressible gas capable of storing a large amount of potentially hazardous thermal energy. Hazards associated with the SPRSs include the following:

- high-temperature and high-pressure gas
- superheated liquid
- hot surfaces
- extreme noise levels
- potential explosions or ruptures of steam piping and equipment due to overpressure or condensation-induced water hammer effects

To mitigate these hazards, workers are required to follow approved procedures and wear the appropriate PPE, including eye and hearing protection, gloves, safety shoes, and other types of approved clothing when working around steam systems. Additional measures taken to protect the health and safety of workers involve implementation of lockout-tagout, asbestos removal, hoisting and rigging, and hot-work procedures. The work site is also posted and access to surrounding areas is restricted.

The ORNL Utilities Division is responsible for operating these stations. Training for these operators includes 2519 Auxiliary Operator Qualification training and on-the-job training. Workers involved in maintaining and repairing these stations receive lockout-tagout training, asbestos removal training, hoisting and rigging training, and other types of health and safety training, as necessary.

Between 2006 and mid-2009, 44 stations were renovated as part of the SPRS Safety and Energy Efficiency Improvement Project. These specific stations were selected and scheduled for renovation based on an engineering evaluation that considered (1) estimated energy loss, (2) maintenance history, (3) urgency of needed repairs, (4) serviceability, (5) worker safety, and (6) facility needs. Each renovation complied with applicable national consensus codes and standards, UT-Battelle engineering standards and welding specifications, and DOE's Worker Health and Safety Program requirements. Information pertaining to each station was compiled by the Fabrication, Hoisting, and Rigging Division (FHRD) surveillance supervisor and stored in a separate folder for future reference. This information included building contacts, floor plan and general building information, work plans, maintenance job requests, lift plans, hot work permits, material lists, certified material test reports, fabrication drawings, weld maps, weld travelers, photographs, permits and test documentation. Information in each folder will be entered into the MAPINFO database by the ORNL Utilities Division for electronic storage and retrieval. Common problems identified during the renovation of these stations are summarized in Table 15. Many stations had multiple problems that adversely affected operations, safety, or energy efficiency.

Table 15. Common problems and potential impacts at SPRSs

Problem	Problem description	Potential impacts
1	Deficient pressure relief device	Increased risk of system overpressure resulting in unplanned steam release (scald and shrapnel hazard)
2	Nuts and bolts are the wrong type based on applicable code requirements or plant specifications	Bolt or nut failure resulting in unplanned steam release (scald and shrapnel hazard) and code compliance issues
3	Undersized valves installed upstream from control valve	Reduced pressure reducing valve performance
4	Shutoff valve located upstream or downstream of pressure relief device	Increased risk of system overpressure resulting in unplanned steam release (scald and shrapnel hazard)
5	No double isolation valves	Unsafe work conditions involving lockout-tagout procedures and unnecessary disruptions in service to the customer to perform station maintenance
6	Improper or no bypass around pressure control valve	Special start-up procedures requiring unnecessary operator intervention and unnecessary disruptions in service to the customer to perform station maintenance
7	No pressure gauges	Increased risk of injury due to unplanned steam release (scald hazard)
8	No pig tails or snubbers and no vent valves on pressure gauges	Reduced reliability of pressure gauges and increased risk of injury due to unplanned steam release (scald hazard)
9	Improperly sized pressure gauge (e.g., use of 300 psig capacity pressure gauge on 15 psig steam line)	Increased risk of injury due to unplanned steam release (scald hazard)
10	No blow-down piping	Special start-up procedures requiring unnecessary operator intervention to avoid water hammer effects due to interactions between cold water and steam
11	No strainer	Reduced control valve and steam trap service life and unnecessary disruptions in service to the customer to perform station maintenance
12	Improper use of strainer blow-down piping as steam supply line for steam jet applications	Increased risk of injury due to unplanned steam release (scald hazard) resulting from equipment failure
13	Improper fitting type and material based on applicable code requirements	Fitting failure resulting in unplanned steam release (scald and shrapnel hazard) and code compliance issues
14	Improper use of concentric reducers for eccentric reducer applications	Fitting failure resulting in unplanned steam release caused by water hammer effects (scald and shrapnel hazard), reduced service life of control valve, unnecessary disruptions in service to the customer to perform station maintenance, and code compliance issues
15	Improper pitch on steam or condensate lines	Reduced service life of control valve and unnecessary disruptions in service to the customer to perform station maintenance

Table 15. (continued)

Problem	Problem description	Potential impacts
16	Improper pipe schedule and material based on applicable code requirements	Pipe failure resulting in unplanned steam release (scald and shrapnel hazard) and code compliance issues
17	Improper design and installation of steam station based on engineering standards	Pressure system failure resulting in unplanned steam release (scald and shrapnel hazard) and code compliance issues
18	Insufficient preventative maintenance	Reduced control valve and steam trap service life and unnecessary disruptions in service to the customer to perform station maintenance
19	No hangers or improper hanger type	Pressure system failure resulting in unplanned steam release (scald and shrapnel hazard) and code compliance issues
20	No labels indicating flow direction or medium	Increased risk of injury due to unplanned steam release (scald hazard)
21	Inaccurate, incomplete, or no process flow diagrams, piping and instrumentation diagrams, and pressure system information for SPRS	Increased risk of injury due to unplanned steam release (scald hazard), unnecessary disruptions in service to the customer to perform station maintenance, code compliance issues, and improper worker training based on inaccurate or insufficient system-specific information
22	Pressure relief device with insufficient capacity	Increased risk of system overpressure resulting in unplanned steam release (scald and shrapnel hazard)
23	No pressure system hazards assessment	Non-compliance with 10 CFR 851.21 requirements for hazard identification and assessment
24	Missing or damaged thermal insulation	Increased risk of burn injury, wasted energy, and unnecessary air emissions
25	Leaking valve packing or steam trap	Increased risk of injury due to unplanned steam release (scald hazard), unnecessary disruptions in service to the customer to perform station maintenance, wasted energy, and unnecessary air emissions
26	Asbestos insulation	Increased risk of worker exposure to carcinogenic material

The average cost for renovating the 44 stations is summarized in Table 16. Case studies that describe work performed to upgrade SPRSs for Buildings 3025, 3144, and 2547 are presented in Sects. 7.1, 7.2, and 7.3, respectively.

Table 16. Average cost for renovating ORNL SPRSs

Station category	Parts and labor	Thermal insulation	Total
Small	$12,000	$5,000	$17,000
Medium	$15,000	$5,000	$20,000
Large	$25,000	$5,000	$30,000

7.1 BUILDING 3025 SPRS RENOVATION

The SPRS for Building 3025 is located approximately 8 ft above the first floor in Corridor A1-2. It is a 1 1/2 in. station that reduces the steam pressure from 125 psig to 25 psig. The condition of the station was assessed before renovation, and the problems that were identified are listed in Table 17.

Table 17. Problems with Building 3025 SPRS before renovation

Problem[a]	Problem description
1	Deficient pressure relief device[b]
5	No double isolation valves
11	No strainer
15	Improper pitch on steam or condensate lines
17	Improper design and installation of steam station based on engineering standards
26	Asbestos insulation

[a]See Table 15 for potential impacts.
[b]The replacement pressure relief device set pressure is 25 psig.

Visual examination of the piping revealed no steam leaks and properly installed thermal insulation. Consequently, the SPRS for Building 3025 was not a source of significant wasted energy. The cost for replacement parts and materials for this project was $7,553.

The success of this renovation is characterized by the following intangible performance measures:

- increased productivity
- positive impact on customer satisfaction
- positive impact on quality of services
- improved work environment
- enhanced environmental, safety, and health compliance

7.2 BUILDING 3144 SPRS RENOVATION

Building 3144 is served by two SPRSs located outdoors on the south side of the building. Neither station was installed in accordance with current codes and standards. The stations were also sources of wasted energy.

Station A is a 3/4 in. SPRS that reduces steam pressure from 125 psig to 25 psig. The condition of Station A was assessed before renovation, and the problems that were identified are listed in Table 18.

Visual examination of the piping revealed a leaking bonnet on a steam isolation valve, a leaking pressure relief valve, and properly installed thermal insulation. The amount of 125 psig steam escaping from the estimated 3/8 in. diameter opening in the leaking bonnet and the estimated 1/4 in. diameter opening in the leaking pressure relief valve was 835 lb per hour. Based on 8,670 operating hours per year and a unit cost of $10.81 per 1,000 lb of steam, which corresponds to a boiler efficiency of 84% and a unit cost for boiler fuel of $8.00/MMBtu, these leaks cost $79,000 per year.

The cost for replacement parts and materials for this small SPRS was $8,803; the total cost for the renovation was $17,000.

Table 18. Problems with Building 3144 SPRS A before renovation

Problem[a]	Problem description
1	Deficient pressure relief device[b]
5	No double isolation valves
7	No pressure gauges
9	Improperly sized pressure gauge
11	No strainer
13	Improper fitting type and material based on applicable code requirements
17	Improper design and installation of steam station based on engineering standards
25	Leaking valve packing or steam trap

[a]See Table 15 for potential impacts.
[b]The replacement pressure-relief-device set pressure is 25 psig.

The success of this renovation is characterized by the following tangible and intangible performance measures:

- fuel savings and emissions avoidance
- increased productivity
- positive impact on customer satisfaction
- positive impact on quality of services
- improved work environment
- enhanced environmental, safety, and health compliance

Station B is a 2 1/2 in. SPRS that reduces the steam pressure from 125 psig to 15 psig. The condition of Station B was assessed before renovation, and the problems that were identified are listed in Table 19.

Table 19. Problems with Building 3144 SPRS B before renovation

Problem[a]	Problem description
1	Deficient pressure relief device[b]
5	No double isolation valves
7	No pressure gauges
9	Improperly sized pressure gauge
11	No strainer
13	Improper fitting type and material based on applicable code requirements
17	Improper design and installation of steam station based on engineering standards
24	Missing or damaged thermal insulation

[a]See Table 15 for potential impacts.
[b]The replacement pressure-relief-device set pressure is 15 psig.

Visual examination of the piping revealed no steam leaks; however, thermal insulation was missing from 20 ft of 3 in. steam piping. The estimated heat loss from this portion of uninsulated pipe was 123 MMBtu per year. Based on horizontal steel pipe, 75°F ambient air, no wind, 8,670 operating hours per year, a boiler efficiency of 84%, thermal insulation efficiency of 90%, and a unit cost for boiler fuel of $8.00/MMBtu, the cost for this thermal energy loss due to the missing insulation is $1,100 per year.

The cost for replacement parts and materials for this small SPRS was $8,542, and the total cost for the renovation was $17,000.

The success of this renovation is characterized by the following tangible and intangible performance measures:

- fuel savings and emissions avoidance
- increased productivity
- positive impact on customer satisfaction
- positive impact on quality of services
- improved work environment
- enhanced environmental, safety, and health compliance

Based on estimated energy cost savings and the cost for renovation, the simple payback for the renovation of Station A and Station B was about 5 months.

7.3 BUILDING 2547 SPRS RENOVATION

Building 2547 is served by a 3/4 in. SPRS that reduces the steam pressure from 125 psig to 15 psig. The condition of the station was assessed before renovation, and the problems that were identified are listed in Table 20.

Visual examination of the piping revealed a leaking pressure relief valve and thermal insulation missing from 6 ft of 3/4 in. steam piping. The amount of 125 psig steam escaping from the estimated 1/8 in. diameter opening in the leaking pressure relief valve was 64 lb per hour. Based on 8,670 operating hours per year and a unit cost of $10.81 per 1,000 lb of steam, which corresponds to a boiler efficiency of 84% and a unit cost for boiler fuel of $8.00/MMBtu, these leaks cost $6,090 per year. The estimated heat loss from this portion of uninsulated pipe was 15 MMBtu per year. Based on horizontal steel pipe, 75°F ambient air, no wind, 8,670 operating hours per year, a boiler efficiency of 84%, thermal insulation efficiency of 90%, and a unit cost for boiler fuel of $8.00/MMBtu, the cost for this thermal energy loss due to the missing insulation is $135 per year.

Table 20. Problems with Building 2547 SPRS before renovation

Problem[a]	Problem description
1	Deficient pressure relief device[b]
6	Improper or no bypass around pressure control valve
7	No pressure gauges
9	Improperly sized pressure gauge
10	No blow-down piping
11	No strainer or strainer malfunction
13	Improper fitting type and material based on applicable code requirements
15	Improper pitch on steam or condensate lines
17	Improper design and installation of steam station based on engineering standards
24	Missing or damaged thermal insulation

[a]See Table 15 for potential impacts.
[b]The replacement pressure-relief-device set pressure is 15 psig.

The cost for replacement parts and materials for this small SPRS was $8,088, and the total cost for the renovation was $17,000. Based on estimated energy cost savings and the cost for renovation, the simple payback for the renovation will be less than 3 years.

The success of this renovation is characterized by the following tangible and intangible performance measures:

- fuel savings and emissions avoidance
- increased productivity
- positive impact on customer satisfaction
- positive impact on quality of services
- improved work environment
- enhanced environmental, safety, and health compliance

8. CONCLUSIONS AND RECOMMENDATIONS

The SPRS Safety and Energy Efficiency Improvement Project being performed by F&O is helping ORNL improve both energy efficiency and worker safety by modifying, maintaining, and repairing SPRSs. Since work began in 2006, numerous energy-wasting steam leaks have been eliminated, heat losses from uninsulated steam pipe surfaces have been reduced, and deficient pressure retaining components have been replaced. These improvements helped ORNL reduce its overall utility costs by decreasing the amount of fuel used to generate steam. Reduced fuel consumption also decreased air emissions. These improvements also helped lower the risk of burn injuries to workers and helped prevent shrapnel injuries resulting from missiles produced by pressurized component failures. In most cases, the economic benefit and cost effectiveness of the SPRS Safety and Energy Efficiency Improvement Project is reflected in payback periods of 1 year or less.

Based on SPRS Safety and Energy Efficiency Improvement Project achievements to date, the F&O Directorate recommends the following plan for CPI:

- Inspect all remaining SPRSs.
- Test pressure relief devices on all SPRSs in accordance with the procedure for inspection and test of pressure relieving devices (Ref. 9).
- Identify energy savings potential and safety improvement opportunities.
- Estimate the cost for implementing the SPRS maintenance procedure (Ref. 10).
- Determine the payback in years.
- Prioritize the repair and maintenance work based on safety and economic considerations.
- Request funding authorization.
- Establish a schedule for completing the needed repairs and maintenance work within the budgetary time limits.
- Prepare periodic status reports that quantify energy savings and characterize safety improvements.

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