

MDEP Design-Specific Technical Report

TR-AP1000WG-02

**Technical Report on AP1000 Squib Valves
Design, Construction, Qualification, and Testing
Experience**

Participation

Regulators involved in the MDEP working group discussions:	CNSC (Canada), NNSA (China), AERB (India), ONR (UK), NRC (U.S.)
Regulators that support the present technical report:	CNSC (Canada), NNSA (China), AERB (India), ONR (UK), NRC (U.S.)
Regulators with no objection:	none
Regulators that disagree:	none

Introduction

In this technical report, the Multinational Design Evaluation Program (MDEP) AP1000 Design-Specific Working Group describes the design, qualification, and application of pyrotechnic-actuated (squib) valves used in the AP1000 nuclear power plant. The objectives of this report are to describe lessons learned from these activities for consideration in future design, construction, qualification, and testing of AP1000 squib valves.

AP1000 System Design

The AP1000 pressurized water reactor designed by the Westinghouse Electric Company (Westinghouse) provides reactor core cooling in response to a loss of coolant accident (LOCA) without reactor operator action or pump operation for 72 hours following the event.

The passive core cooling system (PXS) provides borated core cooling from core makeup tanks (CMTs), accumulators, and the in-containment refueling water storage tank (IRWST). For these sources of borated injection to occur, the reactor coolant system (RCS) must be sufficiently depressurized for each source. The automatic depressurization system (ADS) for RCS has dc-powered motor-operated valves (MOVs) for Stages 1 to 3, and squib valves for Stage 4 to reduce the RCS pressure and allow gravity-driven water flow to cool the reactor core in the event of a design-basis accident.

The PXS has four passive injection sources: (1) two CMTs with cold borated water at RCS pressure; (2) two accumulators with cold borated water pressurized at 700 pounds per square inch gauge (psig) [4.83 megapascal (MPa)]; (3) the IRWST with cold borated water vented to the containment atmosphere; and (4) the containment sump for long-term recirculation to the reactor vessel.

The response of an AP1000 reactor to a LOCA includes:

1. As the RCS inventory decreases, two CMTs provide cooling water to the reactor core via actuated air-operated relief valves (AOVs);
2. The ADS reduces RCS pressure as follows:
 - Stage 1: dc-powered MOVs open at CMT Low-2 level;
 - Stage 2: dc-powered MOVs open, after time delay;
 - Stage 3: dc-powered MOVs open, after further time delay; and
 - Stage 4: squib valves open at CMT Low-6 level;
3. During depressurization at 700 psig [4.83 MPa], two accumulators provide cooling water to the reactor core;
4. The PXS injection isolation squib valves open with the ADS Stage 4 signal to provide gravity-driven flow from the IRWST when RCS pressure is sufficiently reduced; and
5. The PXS recirculation squib valves open at the Low-2 IRWST level to provide containment sump flow to the reactor core.

AP1000 Squib Valve Description

The AP1000 reactor includes 12 squib valves to fulfil its safety functions:

- four 14-inch [35.6 centimetres (cm)] ADS Stage 4 squib valves;
- four 8-inch [20.3 cm] PXS injection isolation squib valves; and
- four 8-inch [20.3 cm] PXS recirculation isolation squib valves

Squib valves are single-operation valves that rely on a pyrotechnic charge to propel a piston to shear the pipe cap and allow system fluid to flow through the valve. The AP1000 squib valves are larger and more complex than the squib valves used in operating boiling water reactor (BWR) nuclear power plants. In addition, the ADS Stage 4 and PXS injection isolation squib valves are a part of the pressure boundary of the RCS during normal operation.

AP1000 Squib Valve Design Approach

At the outset of developing the detailed design of the AP1000 squib valves, Westinghouse established a Design Review Team that included experts from a wide range of technical disciplines to evaluate the proposed design for the AP1000 squib valves. Westinghouse and the valve vendor conducted design testing of proposed prototypes to demonstrate their performance capability and to identify design issues with the squib valves. Westinghouse prepared a Failure Modes and Effects Analysis (FMEA) to identify the significant aspects of the proposed squib valve designs.

The American Society of Mechanical Engineers (ASME) Standard QME-1-2007, “Qualification of Active Mechanical Equipment Used in Nuclear Power Plants,” includes provisions for the qualification of power-operated valves to be installed in nuclear power plants. Westinghouse applied ASME Standard QME-1-2007 in preparing the detailed design specifications and qualification plans for the squib valves. The AP1000 squib valve qualification has included seismic and dynamic testing, environmental (including temperature, radiation, humidity, spray, submergence, and thermal aging) and functional flow testing. Westinghouse conducted batch testing of specific parts of the AP1000 squib valves, such as the initiators, pyrotechnic cartridges, and shear caps.

The valve vendor performed separate effects testing on the squib valve initiators to determine whether the initiator output would be impacted by exposure to radiation (both gamma and neutron) or thermal aging. As a result of this testing, the vendor made design changes to the initiator. Testing was also performed to ensure that sufficient margin was being maintained to provide reliable ignition of the initiator over a range of input current signals.

Westinghouse prepared qualification reports for the AP1000 squib valves in accordance with ASME Standard QME-1-2007.

MDEP Common Position AP1000-01

The MDEP AP1000 Design Specific Working Group developed a Common Position AP1000-01, “The Design and Use of Explosive-Actuated (Squib) Valves in Nuclear Power Plants,” (<http://www.oecd-nea.org/mdep/common-positions/PUBLIC%20USE%20DCP-AP1000-01-%20Squib%20valves.pdf>) to communicate a common position among regulators reviewing squib valve designs in order to (1) promote and understand each country’s regulatory decision and its

basis; and (2) aid in the assessment of squib valves that are used to perform a safety function within a nuclear power plant.

The Common Position lists the following principles that are expected to be considered in the design, qualification, procurement and in-service activities (such as examination, inspection, testing and maintenance) of squib valves:

- 1) Evaluate the basis for use of squib valves versus alternative valve types;
- 2) Identify the safety functions;
- 3) Categorize and classify the safety functions;
- 4) Determine the environmental parameters;
- 5) Specify the codes and standards to be satisfied;
- 6) Evaluate the design to perform the safety functions through techniques such as an FMEA;
- 7) Establish the qualification process to support the reliability of the safety functions;
- 8) Establish the qualified life (operating hours, actuations, shelf life, and post-accident life); and
- 9) Determine the Examination, Inspection, Maintenance and Testing (EIMT) requirements

The Common Position informed the regulatory reviews of the design in the member countries of the AP1000WG. Since then, the members applied the concepts considered in their evaluation of the design, qualification, and testing of the AP1000 squib valves.

AP1000 Squib Valve Design Evaluation

U.S. Nuclear Regulatory Commission (NRC) Experience

AP1000 Design Certification

Westinghouse submitted an application for certification of the AP1000 reactor design to the United States (U.S.) Nuclear Regulatory Commission (NRC) under Part 52, “Licenses, Certifications, and Approvals for Nuclear Power Plants,” of Title 10, “Energy,” of the Code of Federal Regulations (10 CFR Part 52). As part of its design certification application, Westinghouse prepared the AP1000 Design Control Document (DCD) which specifies provisions for the design, qualification, and application of the AP1000 squib valves.

The AP1000 DCD Tier 1 includes inspections, tests, analyses, and acceptance criteria (ITAAC) for the ADS Stage 4 squib valves and the PXS injection and recirculation squib valves. For example, the AP1000 DCD Tier 1 includes ITAAC to verify that the AP1000 squib valves satisfy the provisions of the ASME Boiler & Pressure Vessel Code (BPV Code) for structural integrity and hydrostatic testing of the valves. The AP1000 DCD Tier 1 also includes ITAAC to verify that the AP1000 squib valves can withstand applicable seismic and environmental conditions. In addition, the AP1000 DCD Tier 1 includes ITAAC to verify that the AP1000 squib valves are qualified by testing or type testing to demonstrate that they will operate under their design conditions, and that the as-built valves are bounded by those tests.

The AP1000 DCD Tier 2 describes the design, construction, qualification, and testing of the AP1000 squib valves. For example, the AP1000 DCD Tier 2, Section 3.9, “Mechanical Systems and

Components,” specifies provisions for the design, construction, and qualification of the AP1000 squib valves. Section 3.9.3, “ASME Code Classes 1, 2, and 3 Components, Component Supports, and Core Support Structures,” states that pressure-retaining components that are classified as safety-related are constructed according to the rules of the ASME BPV Code, Section III. In addition, Section 3.9.3.2.2, “Valve Operability,” states that the qualification of active valve assemblies is performed in accordance with the ASME Standard QME-1-2007. The NRC Regulatory Guide (RG) 1.100 (Revision 3), “Seismic Qualification of Electric and Active Mechanical Equipment and Functional Qualification of Active Mechanical Equipment for Nuclear Power Plants,” accepted ASME Standard QME-1-2007 for the functional qualification of valves used in nuclear power plants. The AP1000 DCD Tier 2, Section 3.9.6, “In-service Testing of Pumps and Valves,” includes in-service testing (IST) provisions for the AP1000 squib valves in accordance with the ASME Code for Operation and Maintenance of Nuclear Power Plants (OM Code). The AP1000 DCD Tier 2, Section 3.10, “Seismic and Dynamic Qualification of Seismic Category I Mechanical and Electrical Equipment,” specifies provisions for the seismic and dynamic qualification of the AP1000 squib valves. The AP1000 DCD Tier 2, Section 3.11, “Environmental Qualification of Mechanical and Electrical Equipment,” specifies provisions for the environmental qualification of the AP1000 squib valves, as applicable.

The NRC NUREG-1793, “Final Safety Evaluation Report Related to Certification of the AP1000 Standard Plant Design,” and its supplements describe the NRC evaluation of the AP1000 design certification application. Appendix D, “Design Certification Rule of the AP1000 Design,” in 10 CFR Part 52 specifies the certification of the AP1000 design.

AP1000 Combined Licenses

Several applicants for combined licenses (COLs) under 10 CFR Part 52 have referenced the certified AP1000 reactor design in their applications. For example, the Final Safety Analysis Report (FSAR) for Vogtle Electric Generating Plant (VEGP), Units 3 and 4, incorporates by reference the AP1000 DCD with additional provisions. This FSAR incorporates the provisions in the AP1000 DCD for the design, construction, qualification, and testing of the AP1000 squib valves. The NUREG-2124, “Final Safety Evaluation Report Related to the Combined Licenses for Vogtle Electric Generating Plant, Units 3 and 4,” describes the NRC’s evaluation of the VEGP COL application. The NRC issued COLs for VEGP Units 3 and 4 and other AP1000 reactors based on the evaluation of the applicable FSARs incorporating the AP1000 certified design.

The AP1000 COL FSARs state that the IST program for squib valves will implement the provisions of the ASME OM Code as well as incorporate lessons learned from the design and qualification process for those valves. During the licensing process for VEGP Units 3 and 4, the ASME OM Code included only limited surveillance provisions for squib valves that were more applicable to the small squib valves used in the standby liquid control system for BWR nuclear power plants. As a result, the NRC determined that more detailed preservice testing (PST) and IST provisions for the AP1000 squib valves were necessary to support issuance of the AP1000 COLs. Therefore, the AP1000 COLs for VEGP Units 3 and 4 and other AP1000 reactors each include a license condition requiring AP1000 squib valve surveillance as follows:

Implement a surveillance program for explosively actuated valves (squib valves) that includes the following provisions in addition to the requirements specified in the edition of

the ASME Code for Operation and Maintenance of Nuclear Power Plants (OM Code) as incorporated by reference in 10 CFR 50.55a.

a) Preservice Testing

All explosively actuated valves shall be preservice tested by verifying the operational readiness of the actuation logic and associated electrical circuits for each explosively actuated valve with its pyrotechnic charge removed from the valve. This must include confirmation that sufficient electrical parameters (voltage, current, and resistance) are available at the explosively actuated valve from each circuit that is relied upon to actuate the valve. In addition, a sample of at least 20% of the pyrotechnic charges in all explosively actuated valves shall be tested in the valve or a qualified test fixture to confirm the capability of each sampled pyrotechnic charge to provide the necessary motive force to operate the valve to perform its intended function without damage to the valve body or connected piping. The sampling must select at least one explosively actuated valve from each redundant safety train. Corrective action shall be taken to resolve any deficiencies identified in the operational readiness of the actuation logic or associated electrical circuits, or the capability of a pyrotechnic charge. If a charge fails to fire or its capability is not confirmed, all charges with the same batch number shall be removed, discarded, and replaced with charges from a different batch number that has demonstrated successful 20% sampling of the charges.

b) Operational Surveillance

Explosively actuated valves shall be subject to the following surveillance activities after commencing plant operation:

- i. At least once every 2 years, each explosively actuated valve shall undergo visual external examination and remote internal examination (including evaluation and removal of fluids or contaminants that may interfere with operation of the valve) to verify the operational readiness of the valve and its actuator. This examination shall also verify the appropriate position of the internal actuating mechanism and proper operation of remote position indicators. Corrective action shall be taken to resolve any deficiencies identified during the examination with post-maintenance testing conducted that satisfies the preservice testing requirements.
- ii. At least once every 10 years, each explosively actuated valve shall be disassembled for internal examination of the valve and actuator to verify the operational readiness of the valve assembly and the integrity of individual components and to remove any foreign material, fluid, or corrosion. The examination schedule shall provide for both of the two valve designs used for explosively actuated valves at the facility to be included among the explosively actuated valves to be disassembled and examined every 2 years. Corrective action shall be taken to resolve any deficiencies identified during the examination with post-maintenance testing conducted that satisfies the preservice testing requirements.
- iii. For explosively actuated valves selected for test sampling every 2 years in accordance with the ASME OM Code, the operational readiness of the actuation logic and associated electrical circuits shall be verified for each sampled explosively actuated valve following removal of its charge. This must include confirmation that sufficient electrical parameters (voltage, current, and resistance) are available for each valve actuation circuit. Corrective action shall be taken to resolve any deficiencies identified in the actuation logic or associated electrical circuits.

- iv. For explosively actuated valves selected for test sampling every 2 years in accordance with the ASME OM Code, the sampling must select at least one explosively actuated valve from each redundant safety train. Each sampled pyrotechnic charge shall be tested in the valve or a qualified test fixture to confirm the capability of the charge to provide the necessary motive force to operate the valve to perform its intended function without damage to the valve body or connected piping. Corrective action shall be taken to resolve any deficiencies identified in the capability of a pyrotechnic charge in accordance with the preservice testing requirements.

This license condition shall expire upon (1) incorporation of the above surveillance provisions for explosively actuated valves into the facility's in-service testing program, or (2) incorporation of in-service testing requirements for explosively actuated valves in new reactors (i.e., plants receiving a construction permit, or combined license for construction and operation, after January 1, 2000) to be specified in a future edition of the ASME OM Code as incorporated by reference in 10 CFR 50.55a, including any conditions imposed by the NRC, into the facility's in-service testing program.

In the 2012 Edition of the OM Code, ASME incorporated provisions for PST and IST surveillance of squib valves in new reactors that are consistent with the above COL license condition. The NRC has revised its regulations in 10 CFR 50.55a, "Codes and standards," to incorporate by reference the 2012 Edition of the ASME OM Code, including the IST surveillance provisions for squib valves in new reactors. Therefore, the NRC regulations specify IST surveillance provisions for AP1000 squib valves through incorporation by reference of the ASME OM Code consistent with the COL license condition for AP1000 squib valve surveillance.

NRC Regulatory Activities

The NRC regulations in 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," specify requirements for the design, construction, installation, testing, and inspection of AP1000 squib valves. For example, the regulations in 10 CFR 50.55a require that the AP1000 squib valves satisfy the ASME BPV Code and ASME OM Code as incorporated by reference in the regulations. In addition, the NRC regulations in 10 CFR 50.49, "Environmental qualification of electric equipment important to safety for nuclear power plants," include requirements for the environmental qualification of the AP1000 squib valves, as applicable.

The NRC staff observed several Design Review Team meetings and squib valve design tests. These observations allowed the NRC staff to have a clear understanding of the design of the AP1000 squib valves. These activities allowed the NRC staff to recognize the challenges associated with the qualification of the AP1000 squib valves.

The NRC staff conducted several vendor inspections at Westinghouse and their suppliers and testing contractors to evaluate the AP1000 squib valve design and qualification process. For example, the NRC staff conducted vendor inspections to review the design of squib valve initiation circuitry, including the sizing of cables between the squib valve initiating circuitry located in the control room and the valves themselves.

On February 20, 2013, the NRC staff held a public meeting to discuss the need to implement a systematic engineering design process sufficient to identify critical parameters of the pyrotechnic system design and to establish acceptable tolerance ranges for each parameter.

The NRC staff participated in teleconferences and videoconferences with their counterparts in other countries to discuss issues associated with the design verification and qualification of the AP1000 squib valves. The NRC staff also communicated inspection results and provided the status of identified issues during AP1000 MDEP meetings.

The NRC has initiated inspections to evaluate the progress toward completing the ITAAC related to the AP1000 squib valves. In addition, the NRC staff plans to conduct inspections of the functional design, qualification, and IST programs for the AP1000 safety-related valves (including squib valves) prior to fuel load for VEGP Units 3 and 4 using NRC Inspection Procedure IP 73758 (dated April 19, 2013), “Part 52, Functional Design and Qualification, and Pre-service and In-service Testing Programs for Pumps, Valves, and Dynamic Restraints.”

UK, Office for Nuclear Regulation (ONR) Experience

In the United Kingdom (UK), the Office for Nuclear Regulation (ONR) conducted a detailed evaluation of the AP1000 reactor design, including the squib valves. Within the UK, the legal requirement for nuclear power plant design is to reduce risks so far as is reasonably practicable. The ONR evaluated the AP1000 design to determine its suitability for licensing in the UK. The use of appropriate standards and good practice for design, manufacture, operation, examination, inspection, maintenance and testing is part of this assessment. The ONR’s mechanical engineering assessment of the AP1000 squib valve design noted a number of shortfalls in requirements, testing and test data amongst others. These issues are addressed in the ONR Generic Design Assessment (GDA) closeout related to squib valve design substantiation (Ref. 15). The ONR has identified EIMT activities appropriate for the AP1000 squib valves.

Details of ONR’s formal assessment of the AP1000 squib valves can be found at <http://www.onr.org.uk/new-reactors/ap1000/reports.htm>. The Step 2, 3, 4 GDA reports and individual GDA issue closure reports contain specific information on ONR’s assessment of the AP1000 squib valve concept and design substantiation.

Ultimately, ONR concluded in April 2017 that the AP1000 design is suitable for construction on licensed sites in the UK, subject to other regulatory permissions being obtained. This judgement was reached assuming the same squib valve designs and substantiation included in the AP1000 designs proposed for other countries. However, Ref. 15 identifies six “Assessment Findings” associated with squib valves which a future licensee will need to address as part of any project to build AP1000s in the UK.

People’s Republic of China, National Nuclear Safety Administration (NNSA) Experience

AP1000 Design Review

During the review of Sanmen and Haiyang Units 1 and 2 FSARs, NNSA staff focused on equipment qualification (EQ) and reliability technical requirements of valves.

Reliability Demonstration of Squib Valves

To respond to NNSA staff concerns, the Sanmen and Haiyang licensees conducted sensitivity analysis for squib valves to further demonstrate their contribution to the AP1000 overall plant risk by hypothetically increasing or decreasing the squib valve reliability. The results showed that further improvement of the reliability of squib valves would not lead to a notable contribution to the overall plant risk.

Equipment Qualification of Squib Valves

The Sanmen and Haiyang licensees performed the EQ tests of the squib valve in accordance with the requirements of the qualification test program. The NNSA staff did a special review of the EQ results and found that the life of the cable connector assemblies and the position indication switch assemblies was 20 years. This failed to meet the 60-year design life requirement in the qualification program. The licensees committed to develop maintenance strategies and take necessary measures to ensure the squib valves meet the design life requirement.

Impact of Over-vibration of the ADS 4 Piping System on the Qualification of Squib Valves

During the hot functional test at Sanmen Unit 1, the B and D-line pipes of ADS Stage 4 in loop 2 of the reactor coolant system were found to have vibrations beyond the general pipe vibration limit of 12mm/s. The NNSA staff reviewed the analysis of the impact of piping vibration on the structural components (i.e. valve body, bonnet, bolt, shear cap, tension bolt) of the squib valve. The vendor analysed the failure mechanism of the actuator, and conducted supplemental vibration aging tests for the igniter in a two-year life scenario and an 8-year life scenario. The test results were successful.

Inspection Activities

The NNSA staff inspected the manufacturing and qualification test processes of the squib valve by conducting regular inspections. The inspectors observed Westinghouse's QA audit of the vendor and took part in NRC's inspection. The NNSA inspectors and their counterparts from NRC jointly witnessed the final hydrostatic test of the first squib valve for the AP1000 project.

Solutions for Issues of Concern

a) Squib Valve Immersion Test Failure

NNSA inspectors witnessed two immersion tests of the 8" squib valve. The immersion tests both failed, post-testing observations found water inside the valve body during the dismantling of the squib valve for inspection. Westinghouse and the vendor analysed the causes of the failures using finite element analysis, sealing element test and other engineering test and implemented corrective measures including replacing the seal ring, improving the shear cap sealing surface design and enhancing the pre-tightening procedure. The third immersion test was successful.

b) 8" Squib Valve Cable Conduit Damage

During the qualification tests, the 8" squib valve conduit was damaged as a result of stainless steel corrosion. This was due to a number of issues including: Sulfur and Chloride ions released by the heated cable jacket, welding intergranular corrosion cracking, extra stress on the joint caused by misalignment of the clamps, and failure of the support to provide adequate stability. The vibration aging, random input motion, and design basis accident tests were all successfully completed after the vendor took a series of corrective measures including changing the design of cable connection assemblies, replacing several materials, and modifying the structures.

c) 14" Squib Valve Cartridge Misfiring

During the batch acceptance inspection of the shear cap and the tightening bolt, the cartridge explosive load failed, and as a result, the squib valve failed to open. The vendors and Westinghouse analysed the possible causes of the cartridge failure including igniter charging cavity material, foreign materials in propellant, internal disc rupture, combustibility and gas production rate of the Carbon Potassium Nitrate (CPN) powder. The results showed that the distribution of the CPN particle sizes was the root cause of the cartridge misfire. Corrective measures were taken to improve the CPN powder ignitability including modification of the cartridge manufacturing procedure, the CPN powder production procedure, and the CPN drawing and material checklist.

LESSONS LEARNT

The lessons learnt from the evaluation of the design, construction, qualification, and testing of the AP1000 squib valves include the following:

1. It is recognized that to determine an appropriate design process and qualification testing for a First of a Kind (FOAK) component, the use of a Design Review Team with a wide range of technical experts early in the design process adds great value. Early interaction with representatives of the potential nuclear power plant applicants and regulatory authorities should be encouraged.
2. For each squib valve application, reliability requirements need to be established and assessed prior to development of a proposed prototype design.
3. Early in the design process, determine the full range of conditions seismic/dynamic (including flow-induced vibration), environmental (such as temperature, humidity, spray, submergence, and radiation), and functional requirements for the component.
4. A detailed FMEA should be performed to identify the potential failure modes and their effects for all mechanical and electrical parts of the valve, including squib actuator.
5. Adequate margins should be established for reliable squib actuation, actuator capability, valve structural capability, piping and support structural capability, and the valve open flow area to account for design, analysis, manufacturing, and testing allowances and uncertainties.
6. Batch testing of replacement parts, such as initiators, pyrotechnic cartridges, and shear caps, should be conducted to verify the reliability of each part.
7. The adequacy of the prototype design for each mechanical and electrical part (including squib actuator) should be confirmed prior to initiation of qualification testing.

8. The standard codes should include adequate provisions for the qualification and testing of squib valves. For example, the ASME Standard QME-1, 2017 Edition, and the ASME,OM Code 2012 Edition, were updated to cover squib valves.
9. The qualification requirements for squib valves should include provisions for supporting the reliability assumptions, including the establishment of margins between stages within the pyrotechnic system design.
10. The maintenance requirements, feasibility of maintenance, and precautions necessary for maintenance of the squib valves should be considered during the design process. These types of considerations can alter the design features of the squib valves.
11. To determine the service life of the squib valves, the program should include sufficient real-time aging to supplement accelerated aging.
12. The manufacturing process should be qualified at the manufacturing facility for the pyrotechnic material used for the squib valves. If a different facility is used to manufacture additional batches of pyrotechnic material when replacement components or materials are needed; then re-qualification of the pyrotechnic material process should be required.
13. The number of initiator and actuator lot acceptance test pieces must provide sufficient evidence to justify the assumed reliability of the squib valve actuator.
14. The environmental conditions for storage of the raw materials, manufactured propellant and actuator assemblies require appropriate definition and suitable control and monitoring throughout the life cycle of the squib valves.
15. Access to the squib valves for EIMT activities should be verified to be sufficient for those activities. This includes removal of the valves to an appropriate area to perform EIMT activities. In addition, radiation exposure to plant operators during EIMT activities should be included in this consideration. The plant layout should also consider the ease at which the squib valves can be removed for EIMT activities, along with minimizing the complexity of lifts and ease of actuator removal.
16. Testing should allow for the identification of aging and degradation of the squib valve initiator, as well as, the actuator assembly. A testing and analysis program should be designed to obtain the maximum amount of information possible and to inform plant operators of the impact of aging on the squib valves.
17. The electromagnetic environment, based on frequencies of equipment and transmitters tested locally, might not bound other countries where the squib valves are installed in AP1000 nuclear power plants. The location for final installation should be considered and, where necessary, additional testing undertaken.
18. A suitable methodology for testing circuit continuity and resistance of the squib valve initiators should be defined and justified for installed conditions. This should include identification of suitable test equipment.
19. An important factor to consider is the justification for all interfacing aspects of the squib valve design and systems in which they are installed. A specific squib valve safety case document or safety analysis report, describing the various structures, systems and components comprising the systems is recommend to facilitate the regulatory assessment.
20. Establishment of appropriate criteria for mechanical shock loading of the squib valve actuators is required. This includes testing to determine the drop height (or impact force) that leads to detonation of the initiator/actuator. From this, a maximum drop height and visible damage criteria can be established.
21. Squib valve development (design / manufacture) should consider the wider expectations of the nuclear industry. This is particularly significant if the item is intended for sale

internationally. For example, one country's regulatory requirements might not be bounding for others and might require additional and more extensive testing at a later date.

22. As squib valves contain pyrotechnic material, there might be additional non-nuclear regulations or standards that are required to be satisfied.
23. The squib valve experience emphasizes the importance of traceability and quality management processes used in manufacturing. Particular attention should be paid to the supervision of subcontractors in the manufacturing of FOAK safety critical equipment.

REFERENCES

1. ASME *Boiler and Pressure Vessel Code* (available through ASME).
2. ASME *Operation and Maintenance of Nuclear Power Plants*, Division 1 (available through ASME).
3. ASME Standard QME-1-2007, “Qualification of Active Mechanical Equipment Used in Nuclear Power Plants” (available through ASME).
4. MDEP Common Position AP1000-01, “The Design and Use of Explosive-Actuated (Squib) Valves in Nuclear Power Plants,” dated December 3, 2010 (available through MDEP).
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