# ENCLOSURE 3

# FOREIGN EXPERIENCE

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# Foreign Experience

## 1.0 Introduction

Many nuclear regulatory authorities in Europe and other parts of the world require filtered containment venting systems (FCVS) or are currently considering the safety benefit of installing FCVS. Following the accidents at Three Mile Island (TMI) in 1979, and Chernobyl in 1986, FCVS were installed on a significant number of reactors worldwide. After the Fukushima accidents, decisions were made to install FCVS on many more reactors. In Sweden, Finland, Germany, France and Switzerland, regulators have evaluated the technical issues for achieving severe accident mitigation, and averting potential radiation doses to members of the public and land contamination in the event of a severe accident. The conclusions reached in those countries was that severe core damage operating experience warranted increased defense in depth, especially in the ability of the primary containment to passively retain accident fission product releases and manage the hydrogen produced in a severe accident. FCVS were deemed essential safety enhancements and are required by many regulatory authorities.

The U.S. Nuclear Regulatory Commission (NRC) identified filtered containment venting as a possible safety enhancement following the Three Mile Island accident. In 1979, industrial-size fission product filtering was performed only in conjunction with military defense program production and fabrication facilities, using solid filter media such as sand and gravel. Sand and gravel filters were briefly reviewed, in concept, by the Electric Power Research Institute (EPRI) and the NRC, but not pursued further. Filtered containment venting was discussed in NUREG-0660, “NRC Action Plan Developed as a Result of the TMI-2 Accident,” (Reference 1) under task items II.B.5, “Research phenomena associated with core degradation and fuel melting” and II.B.8, “Rulemaking proceeding on degraded core accidents.” However, the items were not included in the TMI-related items approved for implementation by the Commission (Reference 2). After Chernobyl, the issue evolved into Task Item CH3.2, “Filtered Venting,” in NUREG-0933, “Resolution of Generic Safety Issues” (Reference 3). The GSI program stated that work related to filter vents is a non-distinguishable part of the development of accident management strategies and containment performance assessments. In pursuing this issue, the staff was expected to increase its knowledge, certainty, and understanding of safety issues in order to increase its confidence in assessing levels of safety; therefore, the issue was considered to be a licensing issue. The program concluded that staff has been doing that by its involvement in various on-going activities related to severe accidents. Because licensing issues are not considered safety issues by the generic safety issues (GSI) program guidance, filtered venting was not pursued any further under NUREG-0933. Filtering was not seriously considered for the Mark I hardened vents requested in Generic Letter (GL) 89-16 “Installation of a Hardened Wetwell Vent” (Reference 4), since venting the primary containment to atmosphere was intended to prevent and not mitigate core damage.

In the 10 years immediately following TMI, Sweden and other countries pursued FCVS technology based on dry filtering, and on wet venturi scrubbing principles first applied in the 1950s to coal-fired power plant emission scrubbing. As a result, the technical and operational expertise and experience for FCVS mostly resides outside of the United States. Early filtering methods and the improved technologies that are currently available in the market are discussed in Enclosure 4 to this Commission Paper. In April and May 2012, the NRC staff took part in bilateral meetings with representatives from regulatory authorities and licensees in Sweden, Switzerland, and Canada to learn more about the experiences of FCVS in those countries. All three countries had required FCVS prior to the accident at Fukushima. The staff exchanged detailed information with plant operators and participated in walkdowns of FCVS installations at the Forsmark (Sweden), Ringhals (Sweden), Leibstadt (Switzerland), Mühleberg (Switzerland), and Point Lepreau (Canada) nuclear power plants (NPPs).

The staff learned that each of these countries share much in common with respect to FCVS: (1) the regulator requires what are considered reasonable-cost safety upgrades consistent with industry progress in safety technology; (2) the regulator and the licensees agree on strengthening containment integrity as a goal, regardless of the calculated value of core damage frequency, for defense in depth recognizing the uncertainties in probabilistic safety assessments (PSAs); (3) a Level 2 PSA is performed to identify the benefit of severe accident management features to strengthen containment, using a large release and/or land contamination criterion; and (4) the regulator and the licensee agree on features that will (a) prevent core-concrete interaction and liner melt through, by flooding containment and covering core debris with water, and (b) remove heat using the FCVS, which also manages overpressure scenarios (e.g., prolonged station blackout (SBO)), including those resulting from arrested core melt outside the reactor vessel.

The information in this enclosure is based on various sources, including the staff's bilateral meetings and discussions with representatives of foreign countries and walkdown of FCVS installations; CSNI Report 148, "OECD Specialist Meeting on Filtered Containment Vent System" conducted in Paris, France on May 17–18, 1988 (Reference 5); responses from staff questions to nuclear authorities in foreign countries; and information from European Stress Test Reports (Reference 6).

The following describes, in part, the rationale for filtered venting in countries that pioneered the early development of FCVS technology. Sweden is representative of countries that decided early-on to install FCVS, and is discussed at length. Consistent with the purpose of this paper, greater emphasis is placed on the boiling water reactor (BWR) Mark I and Mark II type containments.

## 2.0 Foreign Experience with FCVS

### 2.1 Sweden

There were 12 light-water reactors in the Swedish nuclear power program at the time the Swedish government ordered a comprehensive review of the lessons learned from the TMI accident. In December 1979, the "Report by the Swedish Government Committee on Nuclear Reactor Safety" recommended that all existing Swedish NPPs be capable of withstanding a core melt accident without any casualties or "ground contamination of importance to the population." Many of the experts who authored the report considered that in cases where the containment was threatened by overpressure, controlled release of limited amounts of activity was preferable to a possible catastrophic failure of the containment barrier with a large and uncontrolled release that would likely result.

The Swedish Parliament later established new general guidelines for the country's reactor safety program as part of its 1980/81 Energy Bill, which was reconfirmed in the 1984/85 Energy Bill. According to the 1981 guidelines, the main priority for Swedish NPPs was for operators to remain focused on the prevention of core damage. However, Sweden's reactor safety program also recognized that despite efforts to prevent core damage, accidents involving severe core damage may still occur, and that no matter how small the probability may be for such accidents, measures should be taken to ensure that releases from severe accidents are kept low.

The 1980/81 Energy Bill also required the owners and operators of the Barsebäck NPP, located approximately 20 km from Copenhagen, Denmark, to expedite the installation of a FCVS at the facility. Barsebäck NPP consists of two BWR units with many similarities to U.S. BWR Mark II pressure suppression containments. Sweden later followed up this action by issuing a "regulatory decree," or order, in October 1981, further requiring that the FCVS for Barsebäck be operational no later than 1985. Completion of the project became a condition of its operating license. The bill gave priority to prevention of ground contamination due to the social consequences that can be anticipated in connection with large-scale evacuation. The bill did not provide any avenues, such as cost-effectiveness arguments, for nonimplementation of the FCVS. In a letter dated October 15, 1981, to the owner of Barsebäck, the Swedish Government provided performance requirements for the new filtering system by requiring that 99.9 percent of radioactive isotopes, excluding noble gases, be retained in either the containment or the new filter, when venting during a severe accident. The decree further stated that filtered venting of reactor containments at Sweden's remaining operating nuclear power plants located at Ringhals, Oskarsham, and Forsmark is a future possibility after taking into consideration the experience from Barsebäck's implementation of the FCVS and the research and technical developments underway within the field of severe accidents. The chosen mitigation concept at Barsebäck was based on the FILTRA research project carried out in 1980–1982. The filtered vent at Barsebäck consists of a 10,000 $m^3$ gravel bed connected to the containment of each of the two reactor units. Venting is made feasible through a pipe connected to the upper drywell and via a vent pipe and rupture disc connected to the gas volume of the wetwell. Additional discussion of the filtered venting at Barsebäck is not provided herein as the gravel bed filters are not the current state of art. In addition, the two Barsebäck units were permanently shut down, prior to Fukushima events, over concerns of a severe accident impacting the population centers of Copenhagen in Denmark, and Malmo in Sweden.

Upon request from the Swedish Nuclear Power Inspectorate (SKI), the utilities operating the remaining NPPs provided reports applicable to their plants in 1985, on ongoing severe accident development projects. After reviewing the results of the utility studies and the research conducted under the FILTRA and RAMA programs, SKI and the National Institute of Radiation Protection (SSI) submitted their recommendations to the Swedish government, following which the remaining operating nuclear plants located at Forsmark, Ringhals, and Oskarsham, were given the formal requirements in 1986 for new mitigating systems during severe accidents and were asked to install the mitigating features by January 1989. Forsmark and Oskarsham consist of three BWRs at each site for a total six BWRs of ASEA-Atom design with similarities in concept to BWR Mark I and Mark II, and the Ringhals site consists of one BWR of ASEA-Atom design and three pressurized-water reactors (PWRs) of Westinghouse design. Swedish authorities determined that cost-benefit considerations would not be the deciding factor in whether or not to ultimately require a FCVS at Forsmark, Ringhals and Oskarsham. This conclusion was consistent with a 1981 decision by the Swedish government that "such measures should be taken even if they involve a not insignificant cost for the owners, as seen in relation to the reduction of the release risk."

The basic guidelines and criteria for severe accident management and release mitigations measures at the Swedish NPPs are:

- There shall be no early fatalities resulting from radiation injuries.

- Ground contamination that would make it impossible to use large areas for long periods of time shall be prevented.
- Events with extremely low probabilities such as major reactor vessel ruptures need not be considered.
- The same basic requirements with regard to the maximum radioactive release are to apply to all reactors, regardless of location or power output.

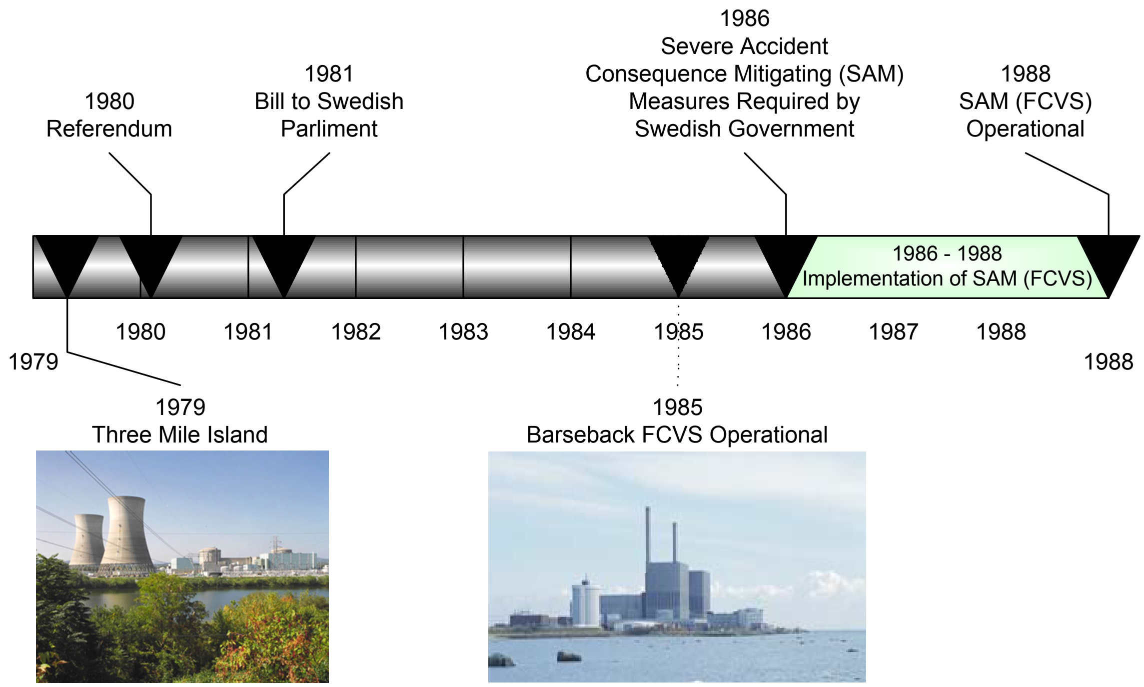



**Figure 1 – Implementation of severe accident consequence mitigating measures in Sweden**

The Swedish BWRs consist of two types: BWR-A, in which the lower section of the containment forms the condensation or suppression pool covering the whole bottom area, somewhat similar to a GE BWR Mark II; and BWR-B in which the condensation pool is annular and the space below the reactor vessel (lower drywell) is dry, somewhat similar to GE BWR Mark I. The analysis of core melt progression and possible radioactive releases were performed through the research project RAMA and utility plant specific studies. The frequency of core melt and probability of containment failure, early or late, were analyzed using a PSA. Two cases were considered, Case 1 is a loss of all core cooling due to loss of all AC power, combined with a loss of steam driven feedwater. Case 2 is a large loss-of-coolant accident (LOCA) with degraded pressure suppression function. Case 1 is the main beyond-design-basis event where the core is damaged and measures to mitigate external release from the containment is required. Case 2 is a design-basis event with respect to early containment overpressurization in a BWR. However, emergency core cooling systems and/or electrical power systems are not affected in this case. A separate unfiltered vent will provide the necessary protection against early rapid overpressurization for Case 2.

Sweden investigated several severe accident mitigating strategies, including alternatives to FCVS. This effort led to the identification of a number of measures that could be taken to protect containment integrity during severe accidents. These measures focused on vulnerabilities uncovered by risk analyses related to containment overpressure failure, containment liner/concrete failure from core debris scenarios, and electrical and mechanical penetration failures in the lower drywell that could occur in Case 1 scenarios in BWR-B containments. These measures included:

- Containment over-pressure suppression
- Lower drywell flooding to protect the basement
- Independent containment spray and water fill systems
- Filtered containment venting systems

The new 1986 guidelines led to extensive safety improvements to Sweden's NPPs, including:

- Filtered containment venting for BWRs and PWRs
- Containment overpressure protection for BWRs, an unfiltered vent to relieve pressure from an early and rapid increase in pressure, as discussed above for Case 2. The unfiltered vent is for a design-basis accident case with loss of pressure suppression function.
- Lower drywell flooding from the wetwell by opening dump valves
- Independent containment spray and containment water filling from an external source
- Containment instrumentation for severe accidents (radioactivity, temperature, pressure, water level, hydrogen concentration)
- Containment penetration shielding in lower drywell for BWRs

To address severe core damage, licensees were also required to prepare plant-specific strategies in order to protect the reactor containment function and to allow the reactor to reach a stable condition where the core is cooled and covered by water. The containment function was required to remain intact during the first 10 to 15 hours after core damage.

The 1986 guidelines also limited radioactive releases to the environment to a maximum 0.1 percent of the reactor core content of Cesium-134 and Cesium-137 in a reactor core of 1,800 MW thermal power, provided that "other nuclides of significance, from the use of land viewpoint, are limited to the same extent as Cesium." This release limit is well below 200 terabecquerel (TBq) and results in a very limited area (considered much less than 50 $km^2$ off site) for potential first year dose resulting from ground contamination of greater than 50 mSv. Accordingly, filtered containment venting through an inerted multi-venturi scrubber system (MVSS) needed to have a decontamination factor (DF) of at least 100 for BWRs and 500 for PWRs to meet the 1986 guidelines.

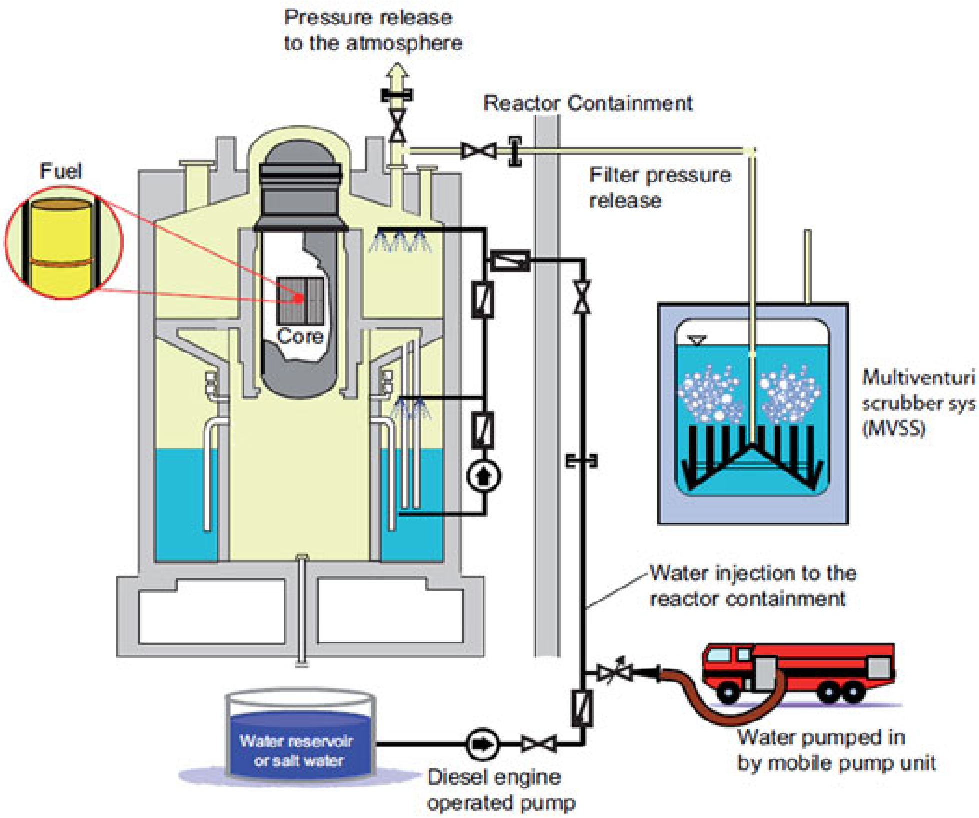



**Figure 2 – Severe accident mitigating measures at BWRs in Sweden**

According to the Swedish analysis, several potential threats to containment integrity occur during the core melt process. These threats are categorized as: (1) pressure loads due to gas and steam generation, (2) temperature loads due to the high temperature of the molten core, (3) impulse loads due to the interaction between the molten core and water, and (4) concrete ablation due to interaction between the high temperature corium and concrete.

In Sweden, the chosen severe accident design scenario is an SBO, further defined as a loss of all AC, and loss of steam-driven pumps, with no manual actions credited during the first 8 hours. Without manual actions or mitigating systems, this scenario will typically result in serious core degradation within 1 to 2 hours; reactor pressure vessel failure within 2 to 4 hours, followed by containment overpressurization and gross failure of containment with large releases of fission products, unless mitigating measures are taken.

In the design scenario for BWRs, the pressure in the containment will not reach the design pressure within 8 hours and the actuation of an independent containment spray (ICS) at this time will significantly delay the overpressurization of the containment until more than 24 hours. Somewhat later, the FCVS is assumed to be actuated manually, but in case of no manual actions, the FCVS is automatically actuated through the bursting of a rupture disc.

However, if no other means of cooling of the containment becomes available, the ICS injection cannot continue indefinitely because it will fill up the containment and, thus, it is terminated after approximately 30 hours. The pressure will then rise and there will be repeated activations of the FCVS with an energy balance established with “feed-and-boil” with the ICS intermittently injecting water and the FCVS dissipating energy through a filtered release of steam. The ability to passively (no operator decision or action required) prevent a containment overpressurization is an important feature for protecting containment integrity in Sweden (Reference 6a).

Operational Findings from Forsmark and Ringhals

In April 2012, members of the NRC staff participated in bilateral meetings with representatives from the Swedish Radiation Safety Authority (SSM) and Vattenfall AB, the licensee for Forsmark and Ringhals NPPs. During this time, the staff had the opportunity to ask questions, exchange information, and perform walkdowns of the FCVS at Forsmark, Unit 1, and Ringhals, Unit 2. The staff gained considerable knowledge and valuable insights into filtered containment venting at the facilities. These insights included:

- Sweden considered the following alternatives before choosing FCVS
  - Pressure relief without filter
  - Filtered pressure relief using a small sand filter
  - Pressure relief of residual heat removal system to avoid a containment bypass flow path
  - Sprays and containment (under pedestal) flooding systems
  - Other improvements to avoid containment leakage
  - Administrative measures

- High filter efficiencies were required to meet the 1986 guidelines to limit radioactive releases to a maximum 0.1 percent of the reactor core content of Cesium-134 and Cesium-137 in a reactor core of 1,800 MW (thermal power).

- Representatives from SSM and Vattenfall stated that Sweden considered various alternatives to filtered venting, and that they would still choose FCVS due to the uncertainties of these alternatives to provide a reliable means to decontaminate aerosols. They generally believe that FCVS is a cost-effective solution to the prevention of land contamination.

- Installation costs (in 1988 dollars) were estimated be approximately $12.5 million per unit at Forsmark and approximately $9 million per unit at Ringhals NPPs.

- Vattenfall representatives estimated that annual maintenance, testing, and inspection costs for the FCVS is approximately $10,000 to $30,000 per unit.

- FCVS is included in plant technical specifications. Allowed outage times (AOTs) are 30 days.

- Licensee representatives did not consider design obstacles to be significant, and the system was designed to be largely independent of existing plant systems in order to minimize construction costs and any loss of electrical production as a result of possible increases in refueling outage-related delays.

- The FCVS was located immediately adjacent to the reactor building and is physically separated from other plant mitigation equipment. In addition, the filter is constructed of concrete and provides significant radiation shielding to plant workers following an accident. Thus, the licensee and SSM officials did not see any concerns regarding an adverse impact from the FCVS to plant workers due to high radiation doses.

- The investigations of severe accidents at the Swedish plants were summarized in a report called “MITRA.” MITRA summarizes PSA studies of potential improvements for a number of initiating events. The initiating events studied included transients, LOCAs, external events, and internal events.

- PSA-studies also included consideration of
  - Filtered containment vents similar to Barsebäck with a 99.9 percent removal efficiency (1,000 decontamination factor)
  - Diversified containment spray system

Current Regulatory Requirements

The regulatory approach adopted in Sweden by SSM has been described as being more process-oriented and is less prescriptive. Regulations provide general requirements that focus on the required licensee processes and the outcome of these processes. Regulatory guidance documents provide only limited details on how licensees are to perform the various process requirements.

The most current regulations regarding nuclear power plants, SSMFS 2008:17, “The Swedish Radiation Safety Authority’s Regulations Concerning the Design and Construction of Nuclear Power Reactors,” are intended to provide more explicit requirements instead of more generalized guidelines for the industry. The new regulations pertaining to severe accident mitigation and FCVS now include:

- Additional requirements needed for modernization of nuclear facilities.
- A definition of “highly improbable events.” These are events which are not expected to occur. However, if the event should nevertheless occur, it can result in major core damage. These events serve as the basis of the nuclear power reactor’s mitigating systems for severe accidents.
- Chapter 5 of SSMFS 2008:17 states that the “reactor containment shall be designed taking into account phenomena and loads that can occur in connection with events in the event class highly improbable events, to the extent needed in order to limit the release of radioactive substances to the environment.” To meet the requirement in Chapter 5, a safety evaluation is to be performed for events and phenomena that may be of importance for containment integrity following “highly improbable events.”

In other words, current regulations require containments to be able to perform their intended safety function following a severe accident, and licensees are required to have mitigating systems to limit radioactive releases to the environment in the event of core damage. The present regulatory framework for FCVS was guided by a study regarding the impacts of cleanup efforts following the Chernobyl accident.

## 2.2 Finland

Finland operates four NPPs, two PWRs at Loviise site of VVER-40 design with ice-condenser containments, and two BWRs of AB ASEA-Atom design at Olkiluoto site with containments somewhat similar to a GE BWR Mark II. A new AREVA PWR unit is currently under construction at Olkiluoto. The following information is based on the staff’s understanding of

Finland's filtered venting requirements and its National Report on European Stress Tests for Nuclear Power Plants (Reference 6b).

Filtered containment venting systems are not installed on the Loviise units due to concerns that venting could lead to sub-atmospheric pressures and possible collapse of the containment. Filtered containment venting systems were installed at the two operating BWRs, Olkiluoto Unit 1 and Unit 2. The plant was modified due to STUK requirement in 1986 (after the Chernobyl accident) that the containment of operating Finnish plants must be equipped with systems ensuring containment integrity in severe accidents. Severe accidents were not part of the plant's original design basis. FCVS were installed in 1990 at both units as a plant modification.

- The design purpose of the filtered vent is to decrease the containment pressure in severe accident sequences when energy and fission products are released into the containment, if the pressure exceeds a specified limit.

- System components include:
  - A vent line from the wetwell equipped with two manually operated valves in series and connected to the filter unit, with valves normally closed.
  - A vent line from the drywell, which is divided into two parallel lines, one equipped with two manually operated valves in series and connected to the filter unit, with valves normally closed, and the other equipped with a break disc and two manually operated valves in series and connected to the filter unit, with valves normally open.

- The reasoning behind the manual valves is that requiring electric power to the accident management system is inconsistent with the postulation that a total loss of power is the most probable cause of a severe accident, and more so because the filters do not depend on power.

- The valves are not optimally located because of reliance on existing valves. The locations require workers to climb several stairs to access the valves. Mechanical remote operation handles and protection to operators from doses were considered in the design.

- Venting is only required if the power outage lasts for about seven hours or more after the core has melted, and decay heat removal from the wetwell cannot be started.

- Lower drywell can be flooded by gravity feed from the wetwell.

- The exhaust gas line from the filter unit is filled with nitrogen.

- The filter unit is a wet scrubber system with chemical control and fine steel fibers to prevent the water droplets from escaping the filter tank.

- Containment filtered venting in severe accidents is actuated by opening of the break disc at 0.55 MPa containment pressure. The system can also be actuated by opening the manual valves from wetwell or drywell. Use of the system is included in the severe accident procedures.

The capacity (thermal hydraulic design) of the filtered venting system is 12 kg/s of saturated steam at a containment pressure of 0.6 MPa and 6 kg/s at 0.3 MPa. The corresponding containment heat removal rates are 25 MW and 12.5 MW. These decay heat levels will be reached in approximately 5 and 60 hours, respectively, after reactor shutdown. The design criteria of the filter were that the release would start at 8 hours, continue for 16 hours, and terminate at 24 hours. It is assumed in the Olkiluoto 1 and 2 severe accident management that AC power is restored at 24 hours and the decay heat would be removed by the containment cooling system after that. The filter unit and the piping up to the filter is designed and insulated so that makeup of scrubber water is not required for a period of 24 hours.

The filter unit must be capable of arresting at least 99.9 percent of the particle activity of the gas and 99 percent of the gaseous iodine. Capability of the unit to reach these values has been verified by testing at the manufacturer (KWU Siemens). The system is not as effective for gaseous organic iodine compounds, with only 60–80 percent of these arrested.

Installation and maintenance costs were not available to the NRC staff. Since the system is passive, STUK believes the maintenance costs are limited.

Olkiluoto 3 under construction will have a similar system. The requirements of the system have changed since 1990. According to present Finnish regulation, it is not allowed to design the filtered venting system as the principal means for decay heat removal from the containment. The system should be used in a very late stage of the severe accidents (after about 1 week) to remove noncondensable gases from the containment and by this means to decrease the containment pressure and subsequently fission product leakage. A separate system for containment heat removal in severe accidents must be provided

## 2.3 Germany

After the Fukushima events, Germany terminated the licenses for power operation of seven older plants (BWRs and PWRs) commissioned before 1980, by the amended Atomic Energy Act on August 6, 2011. Currently, there are eight PWRs and two BWRs operational in Germany. There are no regulatory standards that require FCVS at German NPPs. However, in the aftermath of the Chernobyl disaster, German utilities decided in December 1986 to voluntarily install FCVS in all PWRs and BWRs. Germany shares a similar philosophy with Sweden in that, while the prevention of core damage is the priority, the mitigation of severe core damage must be considered by licensees.

The decision for filtered venting systems was based, in part, on plant-specific accident analyses that considered containment venting systems to be relatively important accident management systems. The analyses showed that:

- The most frequent severe accidents are likely to lead to a medium or long-term containment failure.
- If severe core damage can be stopped or if an early containment failure can successfully be prevented, there still remains the potential for late overpressure failure.

Other advantages of FCVS at German NPPs cited by Germany's participants at the Organization for Economic Co-operation and Development (OECD) Specialist Meeting on Filtered Containment Venting Systems (Reference 5), included:

- Beyond-design-basis plant conditions are difficult to predict. With increasing plant degradation during a severe accident, the uncertainties regarding relevant phenomena, further development of the accident, and possible containment failure modes increase considerably.
- Risk assessments predict lower releases of fission products to the environment, because the release path is through filters, and the containment release pathway can be closed.
- Flexibility for plant personnel is increased substantially. Although venting may be designed to cope only with one specific goal (e.g., the avoidance of an overpressure failure) FCVSs can be used for several purposes, (e.g., decay heat can be removed before a basemat melt-through, containment pressure can be reduced to minimize the flow into the ground, and containment atmosphere can be purged, if desirable.)

The German Reactor Safety Commission (RSK) specified the requirements for filtered containment venting in December 1986 for PWRs, and June 1987 for BWRs. Venting flow (gas and steam) at saturated steam conditions shall correspond to 1 percent of the thermal reactor power. The basis for the 1 percent heat removal is that it corresponds to the decay heat rate after the entire heat capacity of the pressure suppression pool is utilized. The RSK specified that FCVSs must be able to remove 99.9 percent of all aerosols and 90 percent of all elemental Iodine. To meet these requirements, many German PWRs were equipped with dry filter systems. The dry filter systems comprised primarily of a series or packs of metal fiber fleeces with decreasing fiber diameters that were installed upstream of conventional HEPA filters. In addition, Germany developed its own “wet filter method” to clean fission products resulting from severe core damage. The German wet filters include a venturi scrubber system with a metal fiber droplet/mist/particle filter unit similar in design to the FILTRA/MVSS systems developed in Sweden (Reference 7).

The vent line in BWRs is connected directly via a line coming from the suppression pool. The procedure for filtered containment venting is described in the emergency procedures manual. The aim of containment venting is to reduce pressure in the containment from approximately the design pressure to half that value. It is estimated that this process in a BWR takes approximately 10 to 20 minutes.

The critical containment pressure for venting is 1 to 1.2 times containment design pressure. The FCVS is to be used during beyond-design-basis events with loss of containment cooling. The venting procedure consists of several steps, including consultation with regulatory and civilian authorities, confirmation that containment pressure is ascending, and emission monitoring instrumentation is functional.

Installation and maintenance costs were not available to the NRC staff.

## 2.4 France

France has a significant presence in nuclear power with 58 pressurized water reactors. Following the TMI accident, France took a similar approach as other West European countries. France’s Institute of Radiological Protection and Nuclear Safety (IRSN) established additional procedures to manage accidental situations leading to the loss of redundant safety systems and to limit the accident consequences whatever its cause. These procedures included the management of containment leakage, the suppression of leakage paths in the basemat, and the management of slow containment overpressurization by a filtered containment venting. These procedures led to the installation of sand filter systems in France's PWRs by the early 1990s (Reference 8).

French NPPs are PWRs with large dry containments. They are all equipped with filtered containment venting systems. The purpose of the venting system is to avoid any containment failure in the long-term phase of a severe accident that could for instance be due to overpressure resulting from gases from molten core concrete interactions. The opening of the vent system, which is an ultimate reactor containment protection measure, would not take place until after 24 hours. To prevent or mitigate the risks from short-term containment failure due to dynamic events, other prevention systems are used, such as pressurizer safety valves to limit the reactor coolant system pressure, direct containment heating, and induced steam generator tube rupture, and passive autocatalytic recombiners to limit the loads due to hydrogen combustion.

The FCVS includes:

- A metallic filter inside the containment that can retain a large fraction of the aerosols
- A sand-bed filter outside the containment that retains most of the remaining aerosols

The venting line is heated to avoid steam condensation and limit the risk of hydrogen combustion within the venting line.

The decontamination factors that are credited in safety analyses are derived from small-scale and full-scale (FUCHIA program) experiments. The decontamination factors include 1,000 for aerosol particles, 10 for inorganic gaseous iodine, and 1 for organic gaseous iodine.

IRSN recognizes that significant uncertainties still remain in the evaluation of severe accident consequences and launched, among other actions, the OECD/STEM Project (and its foreseen considered follow-up STEM2) to address the following issues:

- The in-containment source term for gaseous iodine in the mid and long term (STEM Phase 1)
- The stability under radiation of iodine-bearing aerosol particles deposited in containment (STEM Phase 1)
- The transport of ruthenium in case of an air ingress accident with special emphasis on the gaseous ruthenium tetroxide issue (STEM Phase 1)
- The efficiency of presently used filtering media and possible new ones for retention of gaseous species, especially iodine and ruthenium gaseous compounds (STEM Phase 2)

The issue of land contamination and evacuation is addressed in PSA Level-2 studies conducted by IRSN. As for long-term effects such as land contamination, reference is made to the Chernobyl accident. Three thresholds for land contamination based on surface activity of Cesium-137 are used in the analyses, with the highest thresholds (15 and 40 $Ci/km^2$) requiring mandatory permanent relocation. The threshold values are not a regulation but only used for an analysis of consequences.

For 900 MWe French NPPs, the latest version of PSA level 2 studies indicates that no permanent relocation is needed and that the threshold for relocation on a voluntary basis is reached at 4 km from the power plant.

Cost information was not available to the NRC staff. IRSN is performing analyses related to the costs induced by a NPP severe accident for several degrees of severity that include the consequences of the so-called S3 source term which corresponds to what would happen in case of filtered containment venting for a core meltdown accident. Direct on-site (decontamination and material replacement) and off-site (prohibition of foods, long-term sanitary effects) as well as indirect costs will be included in the analyses.

The French Report on European Stress Tests conducted after Fukushima (Reference 6c) indicated potential deficiencies of the filter system, such as the seismic capability (it is not seismically designed after the outboard containment isolation valve) and the adequacy of the system for venting at multi-unit sites. In November 2011, IRSN announced a new approach to ensuring the safety of nuclear installations and a number of measures designed to prevent severe accidents from becoming catastrophic ones as a result of the Fukushima accident. The new measures that were outlined may result in the replacement of some accident management systems, such as the filtered containment vents (sand filters) at French reactors. In announcing the new approach, IRSN stated that the new measures are an implicit recognition that a severe accident can happen, even at plants that have implemented post-TMI and post-Chernobyl accident management measures. The Nuclear Safety Authority (ASN) requested licensees to submit a detailed study of possible improvements to the U5 venting-filtration systems, with respect to their resistance to hazards (e.g., seismic), improved filtration of fission products, consequences of opening the vent on accessibility to the site and on the control room and emergency premises, and risks of hydrogen combustion.

## 2.5 Switzerland

Switzerland has five operating nuclear power plant units, with three PWRs and two BWRs of GE design (a Mark III and a Mark I containment). In April 2012, members of the NRC staff participated in bilateral meetings with representatives from the Swiss Federal Nuclear Safety Inspectorate (ENSI), Kernkraftwerk Leibstadt (KKL) the licensee for NPP Leibstadt (GE Mark III), and Kernkraftwerk Mühleberg (KKM/BKW) the licensee for NPP Mühleberg (GE Mark I). As in Sweden, the staff had the opportunity to ask questions, exchange information and perform walkdowns of the FCVS at Leibstadt and Mühleberg. The following information is based on the insights gained in these meetings, and the Swiss National Report in response to European Stress Tests (Reference 6d).

Although many similarities to the actions taken by Sweden exist, the Swiss took a slightly different approach following the accident at TMI. The Swiss Nuclear Energy Act states that licensees shall backfit to the extent necessary, in keeping with operational experience and currently available technology, to further reduce risk to people and the environment. Following the TMI accident, the Swiss Safety Authority (HSK) did not require FCVS, but it required all nuclear power plants in Switzerland to install other severe accident mitigation systems. For example, at the Mühleberg NPP, the licensee (KKM) installed a bunkered emergency building housing an additional independent emergency core cooling systems. The facility, known as "SUSAN," provided fully redundant and diverse sources of cooling water at Mühleberg beyond what was originally designed for the plant.

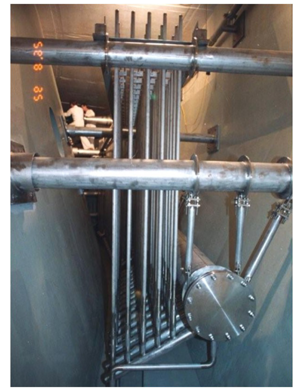
In response to Chernobyl (1986), HSK directed licensees to evaluate the FCVS. By that time, Sweden had made considerable progress on the FILTRA/MVSS effort, and the "wet" containment filters using venturi-type scrubbers were considered the best available technology. HSK required the backfit based on a defense-in-depth argument with the goal of preventing an uncontrolled radioactive release due to loss of integrity of the containment during a severe accident. The FCVS increases the fourth safety layer of defense in depth (onsite accident management). The Swiss Nuclear Energy Act (Article 22, paragraph 2, item g) states that "the licensee holder shall backfit the installation to the necessary extent that it is in keeping with operational experience and the current state of the backfitting technology, and beyond insofar as further upgrading is appropriate and results in further reduction of risk to humans and the environment." FCVS was considered in the Level 2 PSA, but the decision to install FCVS was not based on probabilistic arguments. Uncertainties (e.g., initiating event, human error, severe accident phenomena, system success criteria, emergency response) also did not specifically play any role in the decision to require FCVS. The decision was based on defense in depth and deterministic considerations.

Once the FCVS became a requirement, HSK regulatory guidance was drafted in 1988, with final guidance in 1993 contained in HSK R-40. Plant installations were completed during the 1989–1993 timeframe. The final guidance directed that the designs possess:

- Heat removal capacity of 1 percent thermal power. For PWRs, 0.5 percent thermal power was acceptable.
- Passively actuate via rupture disc so as not to require intervention for 24 hours.
- Allow operation from the control room and separate remote panel. Flow rate though the venting device shall be adjustable.
- Contain their own dedicated power for instrumentation and valve operation.
- Earthquake resistance based on Seismic Class 1 requirements.
- High decontamination factors, 1,000 for aerosols and 100 for elementary iodine (based on available technology)
- Decontamination factors shall be demonstrated on the basis of experiments within a flow rate of 10 percent to 100 percent of the nominal flows. With respect to the expected maximum load on the filters consisting of radioactive and non-radioactive materials, an amount of 150 kg of aerosols is postulated to go into the vent system. A large part of this aerosol mass consists of inactive material.
- Sections of the venting system beyond the second containment isolation valve and ahead of an eventual throttling device shall be deigned to Safety Class 4 (Swiss design rule R-06) and safe-shutdown earthquake. Design pressure shall be a factor of 1.5 times the nominal relief pressure specified above. Consideration of dynamic loads (e.g., condensation shocks) shall be included.
- Conservative consideration of the temperatures to be expected during operation including the possibility of local accumulation of hydrogen gas.
- For BWR Mark I containments, the system should still work after filling the wetwell and flooding the drywell.
- Instrumentation for the venting system shall work in stand-alone mode for 100 hours.

Operational Findings in Switzerland

- Installation costs were estimated to be approximately $11 million (1993 dollars) at Leibstadt, and $6 million (1990 dollars) at Mühleberg. The primary reason for the significantly lower cost for the FCVS at Mühleberg was due to the plant's unique design. Mühleberg has a second "outer torus" that provides pressure suppression capability for the secondary containment similar to that provided by the suppression pool in BWR primary containments. As a result, KKM/BKW was able to take advantage of the outer torus to install venturi-type scrubbers, as shown in the picture to the right.



- Estimated cost for maintenance, testing, and inspection costs for the FCVS is approximately $50,000 to $100,000.
- FCVS is included in plant technical specifications. Allowed out-of-service time is 10 days.
- Enhanced water chemistry is planned to improve iodine retention.
- As in Sweden, licensee representatives did not consider design obstacles to be significant, and the system was also designed to be largely independent of existing plant systems in order to minimize construction costs and any loss of electrical production as a result of possible increases in refueling outage-related delays.

## 2.6 Canada

In May 2012, members of the NRC staff participated in meetings with representatives of the Canada Nuclear Safety Commission (CNSC), NB Power (Point Lepreau Owner/Operator), and Ontario Power Generation. During this time, the staff had the opportunity to ask questions, exchange information and perform a walkdown of the Point Lepreau FCVS. As in Sweden and Switzerland, the staff also presented questions to Canadian authorities and licensee representatives.

Point Lepreau is a CANDU 6 that has undergone substantial refurbishment beginning in 2000. In 2007, the regulator and the utility discussed the installation of a FCVS similar to those on Swiss plants for severe accident management. The value of a FCVS was assessed by the licensee in a complete Level 2 PSA, including external events, in accordance with CSNC Regulatory document S-294. The analysis uses severe core damage frequency (SCDF), and large release frequency (>1 percent Cs-137 inventory) as decision metrics that align with IAEA SSG-3 and SSG-4. The FCVS, costing approximately $14 million Canadian, was found to be cost-beneficial when using the large release frequency metric. The stated purpose of the FCVS is "to prevent failure of containment integrity due to the increase of containment pressure beyond the failure pressure" of approximately 220-230 kPa(g) or 31.9 to 33.4 psig.

In Canada, an Integrated Safety Review (ISR) is conducted as part of the regulatory requirements for life extension/refurbishment. The ISR requires that licensees address modern codes and standards and state-of-the art knowledge to enhance safety to a level approaching that of a modern plant. The FCVS at Pt. Lepreau was the option that NB power implemented to allow the SCDF/LRF to be met. NB power considered other options and determined that a FCVS was the optimal solution to reduce the large release frequency below the limit.

The implementation rationale for the FCVS on the CANDU 6 parallels the basis found at other foreign sites visited in Sweden and Switzerland. That is: (1) the regulator requires reasonable cost safety upgrades consistent with industry progress in safety technology, (2) the regulator and the licensees agree on strengthening containment integrity as the goal, regardless of the calculated value of core damage frequency, for defense in depth recognizing the uncertainties in PSA, (3) a Level 2 PSA is performed to identify the benefit of severe accident management features to strengthen containment, using a large release and/or land contamination criterion, (4) the regulator and the licensee agree on features that will (a) flood the containment to prevent core-concrete interaction, liner melt through, cover core debris, and (b) remove heat using the FCVS, which also manages overpressure scenarios (e.g., prolonged SBO), including those resulting from arrested core melt outside the reactor vessel.

Point Lepreau installed an AREVA-designed passive filter next to the containment. This design is significantly smaller than the FILTRA design, with the scrubber tank measuring 6.5 meters high and 4 meters in diameter. The scrubber tank contains venturi nozzles in a sparger array, and a metal fiber filter for micro-aerosols. It is operated by hard-linkage isolation valves from a shielded location. It does have a rupture disk, but an isolation valve in the same path is normally closed. It is designed to retain greater than 99.9 percent of aerosols, greater than 99.5 percent elemental iodine, and greater than 99 percent organic iodine. The filter house is seismically qualified.

The CNSC Fukushima Task Force recommended that similar venting provisions as implemented at Pt. Lepreau be considered for all other Canadian NPPs (Reference 9). During the meetings, the staff learned that Canada is also planning to install a shared filter at the four unit Darlington site. The filter will be designed to handle simultaneous accidents at all four units. Filters under consideration are the AREVA design and Westinghouse dry filter design using metal fiber filter and a zeolite “molecular sieve.”

## 2.7 Japan

There were a total of 54 reactors licensed to operate at the time of the Fukushima accidents. The Fukushima accident caused core meltdowns at three reactors with BWR Mark I containments at the Fukushima Dai-ichi site. Nuclear power in Japan was shut down after the Fukushima accident. Japan’s Nuclear Regulatory Authority (NRA), comprised of five commissioners, unanimously approved a directive on October 10, 2012, to Tokyo Electric Power Company (TEPCO), the owner and operator of the NPPs at the Fukushima Dai-ichi site, to decommission Units 1 to 4, and maintain cold shutdown of Units 5 and 6. As of September 2012, there are only two reactors operating in Japan.

In an announcement on February 7, 2012, the chairman of a committee on nuclear development measures under Japan’s Federation of Electrical Power Companies (FEPC) announced that new vent facilities containing filters would be installed at all nuclear reactors in Japan. The NRA also unanimously approved on October 10, 2012, to formulate regulations to implement the law passed by the Japanese Parliament stipulating that NPP operators must prevent the release of radioactive materials at abnormal levels following severe accidents. The NRA intends to formulate two sets of regulations with regard to detailed design of plant systems and severe accident management procedures aimed at preventing or mitigating those severe accidents.

## 2.8 Taiwan

Taiwan has four BWRs (two GE Mark I and two Mark III) and two PWRs. In an information exchange between the Atomic Energy Council (AEC) staff and the NRC staff at the NRC Headquarters on October 10, 2012, the AEC stated that filtered vents were ordered for their plants in August 2012.

## 2.9 Spain

There are two BWRs (one GE Mark I and one GE Mark III) and six PWRs in operation. The installation of FCVS is currently under consideration in Spain.

## 2.10 Mexico

There are two BWR Mark II units at the coastal site of Laguna Verde. During a visit by the NRC staff members to Mexico in August 2012, the staff was informed that CNSNS is considering what actions they should require.

## 2.11 Belgium

There are seven PWRs in operation. Belgium has included FCVS in the long-term operation project for the older plants (Doel 1 and 2, and Tihange 1), and is studying the requirement for FCVS in the newer plants.

## 2.12 China

There are 14 operating reactors in China, all PWRs. China has been pursuing the construction of 26 new generation nuclear power plants, all PWRs, in different stages of construction. The staff understands that China may be planning to install FCVS on two operating reactors and possibly other new reactors. However, recent press reports indicate that as a result of Fukushima, China may be lowering its target by not building new plants in inland locations, and to only build them in coastal areas.

## 2.13 Netherlands

There is one PWR of Kraftwork Union (KWU) in operation. It is equipped with a wet scrubbing FCVS (Reference 6f).

## 2.14 Romania

The two CANDU 6 units at Cernavoda are operated by Romanian state nuclear power corporation Societatea Nationala Nuclearelectrica (SNN). They began operation in 1996 and 2007. It was announced in January 2012 that AREVA had been awarded a contract to provide its filtered containment venting systems for the two Romanian plants with a completion scheduled for 2013. The AREVA system uses wet scrubbing technology followed by dry metal fiber filters.

## 2.15 South Korea

There are a significant number of operating reactors (various PWR types) and new constructions in South Korea. A South Korean representative attending the International

Society of Nuclear Air Treatment Technologies (ISNATT) meeting in the U.S. in 2012, stated that South Korea has decided to install FCVS on all its containment types.

### 2.16 Other Countries

Hungary, Slovenia, and Slovakia have reactors of western PWR or VVER-440/213 (PWR) design. Hungary stated that FCVS will be one of the many concepts that will be considered for containment overpressure protection (Reference 6g). Slovakia did not mention FCVS as being under consideration (Reference 6i). Slovenia stated that it was considering alternatives to FCVS in its response to the European Stress Tests (Reference 6h); however, Slovenia recently committed to installing a dry filter method FCVS at its only reactor (Krsko), a PWR.

Ukraine has 15 reactors of VVERs type (PWRs) in operation. None of them have FCVS. The National Report of Ukraine on the European Stress Tests (Reference 6k) states that FCVS is one of the measures under consideration for containment overpressure protection.

United Kingdom has many reactors in operation, with only one PWR (Sizewell B) and FCVS for the PWR is under consideration (Reference 6j). The remaining reactors are gas cooled.

Table 1 summarizes the implementation of FCVS in many nations, both BWRs and PWRs, including decisions taken post-Fukushima for future implementation. The table is generally limited to reactors larger than 400 MWe and does not include all countries (e.g., Argentina and Brazil). However, it includes all reactors with BWR Mark I and Mark II type containments. In assessing the status of worldwide implementation of FCVS, the staff relied on news releases from both U.S. and foreign organizations and the European Stress Test Reports.

| Country | Boiling Water Reactors (BWR) by Containment Types | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | GE Mark I | | | | | GE Mark II | | | | | ABB Mark II | | | | | GE Mark III | | | | | Other | | | | | ABWR | | | | |
| | No. of Rx | FCVS Operational | Committed | Considering | No FCVS | No. of Rx | FCVS Operational | Committed | Considering | No FCVS | No. of Rx | FCVS Operational | Committed | Considering | No FCVS | No. of Rx | FCVS Operational | Committed | Considering | No FCVS | No. of Rx | FCVS Operational | Committed | Considering | No FCVS | No. of Rx | FCVS Operational | Committed | Considering | No FCVS |
| Belgium | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bulgaria | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Canada | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| China | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Czech Republic | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Finland | | | | | | | | | | | 2 | X | | | | | | | | | | | | | | | | | | |
| France | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Germany | | | | | | | | | | | | | | | | | | | | | 2 | X | | | | | | | | |
| Hungary | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| India | 2 | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | |
| Japan | 4* | | X | | | 7 | | X | | | | | | | | 3 | | X | | | 4 | | X | | | 3 | | X | | |
| South Korea (ROK) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mexico | | | | | | 2 | | | | X | | | | | | | | | | | | | | | | | | | | |
| Netherlands | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Romania | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Russia | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Slovakia | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Slovenia | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| South Africa | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Spain | 1 | | | X | | | | | | | | | | | | 1 | | | X | | | | | | | | | | | |
| Sweden | | | | | | | | | | | 4 | X | | | | | | | | | 3 | X | | | | | | | | |
| Switzerland | 1 | X | | | | | | | | | | | | | | 1 | X | | | | | | | | | | | | | |
| Taiwan | 2 | | X | | | | | | | | | | | | | 2 | | X | | | | | | | | | | | | |
| Ukraine | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| United Kingdom | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

* Does not include the 4 reactors damaged by the earthquake and tsunami at Fukushima Dai-ichi.

| Country | Other Reactor Designs (non-BWR) | | | | | | | | | | | | | | | | | | | | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PWR | | | | | PHWR/ Candu | | | | | VVER | | | | | Other | | | | | |
| | No. of Rx | FCVS Operational | Committed | Considering | No FCVS | No. of Rx | FCVS Operational | Committed | Considering | No FCVS | No. of Rx | FCVS Operational | Committed | Considering | No FCVS | No. of Rx | FCVS Operational | Committed | Considering | No FCVS | |
| Belgium | 7 | | | X | | | | | | | | | | | | | | | | | |
| Bulgaria | | | | | | | | | | | 2 | X | | | | | | | | | |
| Canada | | | | | | 18 | X | X | | | | | | | | | | | | | |
| China | 10 | | | | | 2 | | | | | 2 | | | | | | | | | | Information is unavailable. |
| Czech Republic | 6 | | | X | | | | | | | | | | | | | | | | | |
| Finland | | | | | | | | | | | 2 | X | | | | | | | | | |
| France | 58 | X | | | | | | | | | | | | | | | | | | | |
| Germany | 11 | X | | | | | | | | | | | | | | | | | | | |
| Hungary | 4 | | | | | | | | | | | | | | | | | | | | Information is unavailable. |
| India | | | | | | | | | | | | | | | | | | | | | |
| Japan | 24 | | X | | | | | | | | | | | | | | | | | | |
| South Korea (ROK) | 17 | | | X | | 4 | | | X | | | | | | | | | | | | |
| Mexico | | | | | | | | | | | | | | | | | | | | | |
| Netherlands | 1 | X | | | | | | | | | | | | | | | | | | | |
| Romania | | | | | | 1 | | X | | | | | | | | | | | | | |
| Russia | | | | | | | | | | | 17 | | | | | | | | | | Information is unavailable. |
| Slovakia | | | | | | | | | | | 4 | | | | X | | | | | | |
| Slovenia | 1 | | X | | | | | | | | | | | | | | | | | | |
| South Africa | 2 | | | | | | | | | | | | | | | | | | | | Information is unavailable. |
| Spain | 6 | | | X | | | | | | | | | | | | | | | | | |
| Sweden | 3 | X | | | | | | | | | | | | | | | | | | | |
| Switzerland | 3 | X | | | | | | | | | | | | | | | | | | | |
| Taiwan | 2 | | X | | | | | | | | | | | | | | | | | | |
| Ukraine | | | | | | | | | | | 15 | | | X | | | | | | | |
| United Kingdom | 1 | | X | | | | | | | | | | | | | 18 | | | | | Other reactor types are gas-cooled. |

## 3.0 Unintended Consequences

In the CSNI Report (Reference 5), Sweden included a section in its presentation titled, "Independence of the filter venting system, eventual implications for the existing plant." Several design considerations for the FCVS were included in this section, including:

- FCVS shall have no detrimental influence on the normal operation
- FCVS shall have no detrimental influence on the other safety functions and systems, especially the isolation of the containment should not be impaired (in particular with respect to design-basis accidents)
- The instrumentation of the venting system has to work in stand-alone mode for 100 hours
- The availability of the system must be assured even in case of failure of electrical equipment not pertaining to the vent system

In addition, Sweden also stated in its presentation:

> The filtered vent is essentially a safety valve function which would come into operation only if the containment pressure significantly exceeds the design pressure. However, the installation of such systems requires attention to its possible negative impact on safety, during accidents within traditional design basis as well as during severe accidents. Situations such as release through inadvertent opening of the vent system and containment sub-pressure as a result of venting non-condensable gases and use of containment spray must be analyzed. By appropriate system design and also operator procedures and training, possible negative impact can be kept a minimum and be clearly outbalanced by the overall benefits.

In the bilateral meeting with the staff, representatives from SSM and Vattenfall did not identify any drawbacks or unintended consequences to FCVS. The system was designed to be independent of other plant systems, including systems installed to mitigate the consequences of severe accidents. As a result, there was no interference with other safety systems. Also, the Vattenfall engineering staff did not discover any concerns regarding on-site radiation release, seismic hazards, or maintenance problems (e.g., system corrosion).

The staff understands that Germany may have identified a possible deficiency of the FCVS. It has indicated that, in some plants, the venting mass flow is not guided via a separate line to the end of stack; instead, it is mixed with the off-gas at the stack entrance. This would possibly allow that explosive H2-gas mixtures are released to buildings before they reach the vent outlet port. Germany has also indicated that it may provide further details in its ENSREG Stress Test in addition to the already-performed national stress test on the venting system design.

## 4.0 Summary

The staff notes that most countries did not rely on cost-benefit analysis to require FCVS on NPPs. The regulatory approach to severe accidents in many countries requires multiple improvements, such as accident management procedures, making equipment available to mitigate the accident (e.g., flooding, $H_2$ control), and training procedures, with filtered containment venting as one component. No single improvement would provide adequate management of severe accidents. To a large extent, they are interdependent for a successful management of a severe accident. The FCVS is an important aspect of the improvements, because it provides flexibility for the operators to vent the containment for unforeseen sequences without being overly concerned about releases. The preferred option is to keep containment intact without venting. However, filtered containment venting is considered a final option preferable to uncontrolled leakage or failure of containment if pressure within containment rises above the normal design pressure. Additional insights gained by the staff include:

- The regulator and licensee agreed on strengthening containing integrity as a goal, regardless of the calculated value of core damage frequency, and to improve defense in depth recognizing the uncertainties in PSAs.

- A level 2 PSA is performed to identify the benefit of severe accident management features to strengthen containment, using a large release and/or land contamination criterion.

- The regulator and the licensee agreed on features that will:
  (1) flood containment to prevent core concrete interaction, liner melt through by covering the core debris with water, and
  (2) remove heat by the FCVS, thus managing overpressure scenarios

- The regulator requires what are considered reasonable-cost safety upgrades consistent with progress in safety technology

The issues discussed under Section 4.0, “Unintended Consequences,” are resolvable through consideration in the design and operation of the FCVS. The foreign countries did not consider them to be serious enough to question the need for FCVS. Within the U.S., existing plant procedures for venting containment results in the venting of non-condensable gases. As such, the addition of FCVS does not introduce a new vulnerability. Rather, the vulnerability of containment implosion due to the removal of non-condensable gases already exists and is actively managed and minimized through plant procedures and controls.

A number of countries in Western Europe have provided FCVS on both PWRs and BWRs. Canada started implementing FCVS on their operating reactors, starting with Point Lepreau in 2007. After Fukushima events, a significant number of countries, including Japan, have started implementing FCVS or declared their intention to proceed with FCVS. A summary of the current status of FCVS worldwide, to the extent information is available, is provided in Table 1. The European Commission press release on October 4, 2012, states that out of approximately 145 reactors in the EU member states, only 32 reactors are not equipped with FCVS. Further, all the EU neighboring countries that responded to the stress tests have already installed FCVS or are in the process of doing so. For pressure suppression containments such as GE BWR Mark I and GE BWR Mark II, the countries that have not made a decision regarding the implementation of FCVS are the U.S., Spain, Mexico, and India.

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