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FILTERED VENTING CONSIDERATIONS IN THE UNITED STATES[1]

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ABSTRACT - The capability to vent with or without attenuation of fission products exists at some U. S. facilities. In addition, two utilities have proposed enhanced capabilities, and generic enhancements are being considered under a regulatory evaluation of severe accident vulnerabilities at all U. S. commercial reactors. The paper 1) summarizes the history of filtered venting in the U. S., including significant past and proposed related research; 2) summarizes an assessment of the positive and negative safety aspects of venting for a class of 24 U. S. reactors (BWR Mark I) and, 3) discusses the regulatory assessments being made of filtered venting as a severe accident management strategy, including potential attributes of both accident prevention and mitigation associated with venting. Lastly, based on a review of available literature on European initiatives, questions are raised; answers to which would significantly help U. S. evaluations.

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DISCLAIMER

1. INTRODUCTION - The purpose of this paper is to summarize the U.S. experience with the use of filtered venting as an accident management strategy. Included is a summary of past and ongoing U. S. research, the results of recent studies on the positive and negative attributes of accident venting for three boiling (BWR) Mark I units (Peach Bottom Units 2 and 3, and Pilgrim), and identification of areas of incomplete information. Filtered vent designs in a number of countries (e.g., Sweden, France, Federal Republic of Germany) employ systems whose major components are located outside of and separate from the reactor building. This is not an essential feature, however. It is important to recognize that the essential elements of a filtered vent already exist in many U. S. reactors. The most notable example are the 40 BWRs operating in the U. S. For these reactors, the water in the suppression pool can serve as an excellent fission product scrubber. However, questions still remain regarding both the effectiveness of hardware and procedures under severe accident conditions, and the overall effect on risk.

2. DESIGN & OPERATIONAL CONSIDERATIONS - Containment venting is used at U. S. reactors for a number of purposes. These include purging during operation, ventilation during shutdown, and for accident management. Two classes of U. S. reactors (24 BWR Mark I units and 9 BWR Mark II units) utilize nitrogen inerting as the primary defense against hydrogen ignition during degraded core accidents. For these plants, filtered exhaust systems are used during operation to control containment nitrogen concentrations, and for purge and ventilation purposes.

Venting in U. S. commercial reactors is generally not contemplated during accidents up to the severity of design basis accidents. Such accidents are generally associated with single failure events, and are not believed to result in any fuel melting. The accompanying fission product releases to the containment would be the noble gases and iodine that had been dissolved in the coolant, and from some fuel pins. This release from the fuel pins is often referred to as gap activity. Releases of fission products to the environment from such events would occur due to containment leakage. Much of the containment leakage, however, would be processed through filtered discharge systems. These same systems could be used to purge containments of residual fission products during and after more serious accidents when containment pressures and temperatures were low enough not to challenge the integrity of the filtered vent systems. They could also be used in accidents with greater challenges, but contamination of spaces and equipment outside containment could occur, and the ability to reclose the vent(s) could be compromised.

Accidents involving fuel melting can produce large quantities of fission products, hydrogen and other noncondensibles. The result could be significant containment pressure and temperature challenges. U. S. studies have indicated that there are a number of important challenges to containment arising from severe accident conditions, each with its associated failure modes:

a) containment bypass (including failure to isolate containment on demand, suppression pool bypass, and interfacing system LOCAs);
b) early overpressure/overtemperature failures both before or shortly after core melting (including those from direct containment heating, non-condensible gas generation and combustible gas (hydrogen etc.) ignition, core/concrete interaction, and ex-vessel molten core/water interactions);
c) early overtemperature challenges from core debris attack on steel containment liners, or steam generator failure (special bypass cases);
d) late overpressure/overtemperature failure, primarily from core concrete interactions; and
e) late overtemperature failures resulting from basemat penetration.

The feasibility and potential benefits of filtered containment venting have been studied by the NRC and its contractors as well as by the nuclear industry. These studies indicate that the benefits depend upon the specific accident sequence. Filtered venting may have positive benefits for those sequences in which the rate of containment pressure rise is relative slow. Filtered venting is less feasible for those sequences resulting in early overtemperature or overpressure conditions. This is because the relatively early rapid increase in containment pressure requires large containment penetrations for successful venting. Venting has also been shown to have the possibility of preventing core melting for accident sequences involving loss of decay heat removal capability (including some anticipated transient without scram sequences). For other sequences, venting has been postulated to increase the likelihood of core damage by causing pump cavitation and the eventual loss of injection to the reactor coolant system. Finally, filtered venting is not regarded as effective in sequences involving containment bypass, although some have argued that filtered venting could be beneficial in reducing the driving force for such bypass.

Venting as an accident management strategy has been shown to require considerations of the ability to release sufficient energy to influence the course of accidents (size and timing), the ability to open and reclose valves, the effects of reactor building releases on equipment and operator actions, and protection against inadvertent or unnecessary operation.

There are filtered vented containment systems operational on several U. S. research reactors, including the Zero-Power Plutonium Reactor (ZPPR) test facility located in Idaho, and the Fast Flux Test Facility (FFTF) located in Washington. A filtered vent design was also proposed for the now abandoned Clinch River Breeder Reactor (CRBR), and scrubbed venting is being used as an accident management strategy at U. S. BWRs.

The ZPPR test facility [1] utilizes a deep bed of graded sand and gravel as its roof to form a filtered path for plutonium and other aerosols in the event of a core-melt accident. The sand and gravel filter is supplemented by a bank of high efficiency particulate air (HEPA) filters which serve as a secondary filter.

The FFTF scrubbed venting system [2] is part of the Containment Margins System (CMS), and is designed to deal with very low probability events involving the release of primary system sodium, fuel and core debris into the reactor cavity. A system for venting and controlling excessive FFTF reactor containment pressure consists of a 30 inch diameter containment penetration line with two isolation valves located outside of containment. The isolation valves can be remotely operated from the control room and are equipped with key lock switches to prevent unauthorized operation. Downstream of the isolation valves is a combination scrubber/filter system. The scrubbed portion consists of a venturi scrubber utilizing water sprays (with a chemical additive to enhance removal of elemental iodine) to remove an estimated 90% of any particulate. The scrubbed gas then enters five cylindrical filters arranged in parallel composed of polypropylene in a fibrous mat. The fibrous filter is estimated to remove about 99% of the remaining particles. Thus, the combined removal efficiency of the system is 99.9%. The effluent is then released to the stack, after being continuously monitored for gross radioactivity content. The system is designed as safety-related up to and including the outboard containment isolation valve, but is non-safety grade beyond that point.

The design for the now abandoned Clinch River Breeder Reactor (CRBR) included a system to accommodate core melt and core disruptive accidents. The applicant proposed controlled venting of the reactor containment atmosphere through filters as a means of reducing the likelihood of a large uncontrolled release of radioactivity beyond 24 hours. This system, which was to consist of exhaust fans, an air washer, sodium scrubber and water separator, a heater prefilter, a HEPA filter, an iodine absorber bed and an after-filter, reached a preliminary engineering design state.

Within the United States, the only commercial reactors approved to vent during severe accidents are boiling water reactors having water suppression pools. The pool serves to scrub and retain radionuclides. The degree of effectiveness has generated some debate within the technical community. The decontamination factor (DF) associated with suppression pool scrubbing can range anywhere from one (no scrubbing) to well over 1000 (99.9% effective). This wide band is a function of the accident scenario and composition of the fission products, the pathway to the pool (through spargers, downcomers, etc.), and the conditions in the pool itself. Conservative DF values of five for scrubbing in MARK I suppression pools, and 10 for MARK II and MARK III suppression pools, have recently been proposed for licensing review purposes. These factors, of course, exclude considerations of noble gases, which would not be retained in the pool.

Emergency Procedure Guidelines (EPGs) [3], have been developed by industry and approved by the NRC staff for use at U. S. BWRs.

These EPGs were developed in direct response to operating problems identified as a result of the TMI-2 accident, and provide guidance for the development of plant specific emergency operating procedures (EOPs). The EPGs are generic to a range of General Electric designs from BWR 1 through BWR 6, and apply to the Mark I, II, and III containment types. By design, they are mostly symptom-based and call for actions which strive to maintain plant safety regardless of the initiating event.

Primary containment venting is called for by the EPGs for two situations. The first is for hydrogen control (note that Mark III containments have their own special features and procedures in this area). The second situation is for venting to prevent overpressurization and to maintain primary containment integrity. For the latter the operator is instructed to vent the primary containment to reduce and maintain the pressure below the primary containment pressure limit (PCPL). The PCPL is defined to be the lesser of either (1) the pressure capability of the containment, (2) the maximum containment pressure at which vent valves can be opened and closed to reject decay heat from the containment, (3) the maximum containment pressure at which safety relief valves (SRVs) can be opened, or (4) the maximum containment pressure at which vent valves can be opened and closed to vent the reactor pressure vessel. Venting could be from the drywell or wetwell, but wetwell venting is preferred to allow for fission product (excluding noble gases) scrubbing in the suppression pool.

Venting procedures as used within the EPGs are intended as a "last resort" operator action. Uncontrolled increases in the containment temperature or pressure will result in containment failure with unknown results. Therefore, it is felt that a controlled action with defined consequences is preferable to no operator action. The methodology to establish the venting pressure is an equally important consideration. Ideally, the venting pressure could be established solely on the actual pressure capability of the containment. That would delay venting until the last possible time and minimize unnecessary releases. However, considerations associated with actual operating plant constraints tend to reduce the venting pressure (based on the PCPL). As a result, there are plant-to-plant differences in EOPs. This is best demonstrated by looking at the selection of the valves that are in the flow paths to be used for venting. Plants have provided a table of penetrations that will be used in the event of a serious accident. The accepted philosophy is to begin opening valves in the smallest flow path, starting with wetwell penetrations. Failing successful control of the transient, the operator is to increase the diameter of valves that are opened sequentially until even drywell valves (resulting in an unscrubbed release) would become candidates. One licensee has also proposed venting the wetwell through the spent fuel pool to enhance fission product scrubbing after core damage.

Pressurized water reactors (PWRs) also contain systems that could be used for venting to prevent containment overpressurization. The feasibility of utilizing them for that purpose, however, has not been extensively explored. Certain engineered systems such as fan coolers and containment sprays could also enhance the trapping and retention of fission products over and above the effects of natural deposition processes.

3. PROPOSED ENHANCED U. S. APPLICATIONS - Several studies have examined the feasibility of using BWR suppression pools, together with existing equipment and possible modifications, to provide a more effective containment venting system.

In July, 1987, the Boston Edison Co. voluntarily proposed a series of modifications [4] for the Pilgrim plant termed the "Safety Enhancement Program." A goal was to identify and implement plant improvements in response to a draft NRC staff BWR Mark I initiative in a manner which would promote effective use of plant capabilities in the event of a severe accident. The Boston Edison Co. proposed enhancements consisting of 12 physical plant changes, including the installation of a Direct Torus Vent System (from the wetwell air space). In proposing the vent system, the licensee acknowledged that venting is one of the strategies used in the BWR Owners Group EPGs. The design changes provided a direct unfiltered, but scrubbed, vent path from the torus to the main stack bypassing the Standby Gas Treatment System (SGTS) on the torus purge exhaust line. The proposed bypass consisted of an 8-inch line around the SGTS to a 20-inch main stack line. The new line would be designed to ASME III Class 2 standards, and would include DC operated solenoid valves instead of more common AC solenoid valves. This would allow for operation in the event of loss of the emergency diesel generators. To limit the likelihood of inadvertent operation, key lock switches and a rupture disk would be used to control valve operation.

The Long Island Lighting Company (LILCO) has also addressed the issue of venting with the potential installation of their Supplemental Containment System (SCS) on the Shoreham Nuclear Power Plant Station. One of the primary goals of the SCS is to provide a wetwell airspace vent. The mechanism proposed to achieve this is the "FILTRA" design as was installed at the Swedish Barsebeck Nuclear Plant in October 1985. DC battery power would be provided for 48 hours to facilitate post-accident isolation valve operation. The system would be a non-safety grade beyond the containment isolation boundary. The operation of the system would act to promote SRV operation, and to maintain the drywell floor seal integrity, by prohibiting containment pressure from rising above 60 psig.

The licensee for Vermont Yankee, a BWR with a Mark I containment, also examined several containment enhancements in a report [5] to the NRC staff in September, 1986. Included was an assessment of the feasibility and benefits of venting through the suppression pool wetwell for a number of severe accidents. Although concluding that containment venting was not practical with the present plant configuration, the licensee recommended that further study, including consideration of several relatively low-cost modifications, was warranted.

4. U. S. NRC MARK I STUDY - Venting in U. S. BWR Mark I plants has been assessed in several studies to evaluate the effectiveness of existing hardware and procedures. In the draft Reactor Risk Reference Document, NUREG-1150 [8] venting in conjunction with alternate injection sources was credited with lowering to negligible levels the core damage frequency of those accident sequences which include a loss of long-term heat removal. Because of that result, (which is specific to the Peach Bottom Atomic Power Station) those sequences which were identified as dominant contributors in WASH-1400 [10] were found to be insignificant compared to other contributors. For other sequences, however, venting has not been found to be always successful. A study performed at the Idaho National Engineering Laboratory (INEL) evaluated venting procedures that were in draft form for Peach Bottom [6]. A main conclusion was that "based on the draft procedures and equipment in place at the time of the analysis, containment venting has limited potential for further reducing the risk associated with accident sequences currently identified as being important to risk." Reasons for that conclusion included hardware that was unlikely to work effectively in some accident sequences, and the likely contamination resulting from direct discharge to the reactor building. As described earlier in this paper, an improved venting system has been proposed for the Pilgrim plant which includes hard pipe for the flow path and reliable, remotely operated valves. An evaluation of the risk implications of that system, however, was not included in the Pilgrim proposal.

4.a Venting Impacts - A comprehensive evaluation of the potential benefits and negative impacts of venting would presumably provide a quantitative measure upon which to judge the technical merits of venting. The evaluation of venting, however, is not straightforward and several elements need to be considered. First, the hardware that would be used to perform venting and the operability of that hardware should be identified. The conditions to which the hardware would be exposed and its survivability would need to be assessed. The effects on other equipment and instrumentation are also important issues that need to be addressed. Second, from a phenomenological perspective, the vent path needs to be assessed as to whether or not it can perform its intended function (e.g., provide sufficient pressure relief). The effectiveness of the vent path to reduce or filter the fission product release also needs quantification. Third, the operator actions required to vent and the subsequent effects on the environment should be evaluated. Procedures should be reviewed and assessments made of the operators' probability of success in following those procedures. Finally, an evaluation of the effects of venting is needed to provide a measure for risk quantification. Both planned and unnecessary or inadvertent venting need to be assessed for a complete risk profile.

To address the elements of venting outlined above requires the specification of a venting "strategy." The strategy would include specifics on hardware and procedures, and a probabilistic risk basis to allow quantitative evaluations of the change in risk due to venting. Because the number of venting strategies is limitless, any attempt to provide a quantitative measure based on generic input will probably meet with limited success. Even with a completed risk evaluation based on a specific strategy, the uncertainties associated with phenomena, equipment, and the human factor may preclude conclusive statements on the change in risk due to venting.

A qualitative evaluation of venting in Mark I containments was performed to bound the effects of different vent systems on severe accident parameters and risk. Four different vent systems were analyzed in this study. The vent systems were selected to bound the spectrum of existing and potential vent systems. As discussed previously, many hardware and phenomenological issues need to be addressed to design a vent system to operate successfully during severe accidents. Several general assumptions were made for all the vent systems. First, all were assumed to operate successfully and open independently of existing AC or DC power sources. Second, the vent systems were assumed to be capable of relieving the pressure loading during both ATWS and decay power situations. Finally, all vent systems were assumed to be connected to the torus wetwell airspace. Therefore, the fission products would be scrubbed in the suppression pool prior to leaving the primary containment. General features of the four vent systems are presented in Table 1. Specific assumptions about the different systems will be described below.

The first vent system was assumed to be similar to the 18" wetwell hard pipe to ductwork system at Peach Bottom [6]. Similar to the Peach Bottom plant, the pressure is relieved through the nitrogen purge system ductwork, which is expected to fail. For the purpose of a general evaluation of venting strategies, it was assumed that the vent system can be safely opened both before and after vessel failure and without existing on-site AC or DC power. Basically, this was a vent system which discharges into the reactor building (RB) upon actuation. Expert evaluation in NUREG/CR-4551 [7] indicated that the reactor building decontamination factors (DFs) probably range from 1.5 to 2.5 in the absence of a hydrogen burn. Although these DFs are small, source term studies indicated that they do play a role in the offsite consequences. Conversely, hydrogen burns in the RB were hypothesized to sweep out the fission products rapidly with little or no DF. Expert opinion solicited in NUREG/CR-4551 estimated a 20% probability of complete bypass of the RB (DF=1.0) during hydrogen burns. As shown in Table 1, another disadvantage of discharging directly into the RB is the potentially adverse effect on recovery equipment.

The second and third vent systems are variations on a system proposed by Boston Edison Company for the Pilgrim power plant [4]. These vent systems use a hard pipe from the torus to the plant stack. The primary difference from the previous system is an elevated release from the plant stack rather than a direct release into RB. Additional evaluation is needed to quantify the effective DFs with a discharge into the RB versus an elevated release from the plant stack. An elevated release has the advantages of enhanced dispersion prior to reaching ground level. However, it is not clear whether or not this DF is higher than that of a discharge into the RB with a 20%

probability of complete RB bypass. Clearly, an elevated release is better than complete RB bypass. Also, a stack release rather than release into the RB will have much less adverse effect on systems needed for recovery.

As shown in Table 1, one vent system includes a rupture disk whereas the second system does not. It is expected that the rupture disk could substantially change the operation of the vent system. The main restriction imposed by a rupture disk is the inability to vent the containment at low pressures. Postulated reasons for venting at low containment pressure include (a) to reduce the pressure driving force from the containment when anticipating vessel failure with an early drywell liner melt-through, (b) to remove the containment hydrogen prior to vessel failure and early drywell liner melt-through, and (c) to reduce the containment pressure prior to a high pressure vessel failure to prevent an early containment overpressure failure. Obvious advantages of the rupture disk system include (a) suppression of venting during design basis accidents and (b) minimizing unnecessary or inadvertent venting.

The final system considered was a hard pipe vent system with a filter upstream of the plant stack. In all cases, the filtered vent system was assumed to respond similarly to the hard pipe system without a rupture disk. However, depending upon the performance characteristics of the filtered vent system, the consequences would be expected to be lower than the non-filtered hard pipe system. The filtered vent system was included for completeness and to allow the framework for future quantification studies.

4.b Station Blackout Sequences - The Peach Bottom analyses performed for draft NUREG-1150 [8] indicated that station blackout sequences accounted for 86% of the core damage frequency associated with all severe accidents. The change in risk due to venting during station blackouts is discussed here. Both the short term and long term station blackouts are characterized by predicted loadings on the containment that do not result in its reaching the containment design pressure prior to vessel failure. Upon vessel failure, the containment may fail early by drywell liner melt-through, or early overpressurization. Two venting strategies were considered for the station blackout sequences. The first strategy, early venting, was assumed to be implemented sufficiently early to depressurize the containment prior to vessel failure. The containment vent system was postulated to remain open for the entire transient. As mentioned previously, the containment pressure would be expected to be below the design pressure (approximately 60.0 psig) at vessel failure [9]. The recent BWR EPGs do not recommend venting until the primary containment pressure limit (which should be greater than the design pressure) is reached. However, the early venting strategy was considered in order to analyze (a) the benefits and downsides of planned early venting scenarios, and (b) the consequences of early inadvertent venting. The second strategy analyzed was late venting. For the purposes of the present study, late venting was defined as venting after vessel failure. In many cases, the containment pressure was calculated to rise above 60 psig after vessel failure [9]. Consequently, late venting during a station blackout may be recommended to help prevent late containment failure. However, late venting can not prevent an early overpressurization due to the pressure spike at vessel failure.

Table 2 qualitatively assesses the change in consequences for various station blackout scenarios for the four vent systems as compared to the same sequences without venting. Based upon review of consequence calculations from the central estimate* of the draft NUREG/CR-4551 [7] study for Peach Bottom, the consequences from early venting followed by an early liner melt-through were not much different than the non-venting case. In both cases the bulk of the fission products would arrive in the containment after vessel failure, and would be quickly, without scrubbing transported to the RB upon liner melt-through. If the probability of early liner melt-through could be reduced, the next most severe containment failure mode would be early or late overpressurization. This scenario illustrates the primary advantage of early venting, since early venting could maintain low containment pressure prior to vessel failure. Based upon the assumption in note 3 in Table 2, however, the rupture disk system would probably not respond quickly enough and the flow path would not have sufficient flow capacity to prevent an early overpressurization failure, assuming no early liner melt-through. Conversely, if liner melt-through is assumed, early venting would have no clear advantages (or disadvantages) during a station blackout.

Three other station blackout scenarios were considered. First, the case in which AC power is recovered after core damage, but there is no vessel failure considered. Only an early venting strategy was assumed. All vented cases would result in an unnecessary release except for the rupture disk system. As discussed in note 2 in Table 2, the rupture disk was assumed not to fail during the containment loading prior to vessel failure. Although the non-noble gas fission products would be scrubbed, it still represents an unnecessary release. In addition, if an alternate injection source was not established prior to venting, the residual heat removal (RHR) pumps could fail on cavitation or loss of net positive suction head (NPSH) and cause a more severe accident.

Second, a scenario with recovery of AC power and vessel failure, but without an associated containment failure, was postulated . It was hypothesized that early recovery might permit termination of core-concrete interactions. Therefore, the containment would remain intact without venting. Similar to the case without vessel failure,

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*Note that the source terms used as the central estimates in [7] and [8] are presently considered underestimates. The final versions of these references are not expected to present central estimates, but should reflect better estimates of source terms.

venting could result in an unnecessary release (or a more severe accident if an alternate injection source is not used).

The final case considered assumed vessel failure with sustained core-concrete interaction which would lead to a late containment failure. In this case, both early and late venting would allow scrubbing of the fission products prior to release. Late venting would be the preferred option since it allows the maximum time for evacuation. However, the operator would not know in advance whether or not the containment would survive early overpressurization or early liner melt-through challenges.

5. CONTAINMENT PERFORMANCE PROGRAM - Containment venting is just one of the issues currently being evaluated for U. S. nuclear plants. Five NRC staff programs are underway to evaluate and potentially improve severe accident performance. These are;

* Individual Plant Examination (IPE). The IPE program is intended to ferret out plant specific risk outliers for each plant using probabilistic risk assessment (PRA) techniques.

* Accident Management Program. This program will address both accident prevention and mitigation. It will develop improved strategies to reduce accident likelihoods, and will develop strategies to prevent the vessel from being breached and to keep the containment from failing.

* Containment Performance. This program is investigating whether or not hardware and procedural improvements are warranted to reduce the likelihood or consequences of generic severe accident containment challenges.

* Improved Plant Operations. This program seeks to improve utility operations through technical specification improvements, improved emergency operating procedures, systematic assessments of licensee performance, and management reviews of risk significant issues.

* Severe Accident/Source Term Research - This program is providing data for the phenomenological understanding necessary to make decisions or to confirm past decision.

6. U. S. RESEARCH PROPOSED IN A COOPERATIVE PROGRAM BETWEEN INDUSTRY AND THE NUCLEAR REGULATORY COMMISSION -- A program called the Advanced Containment Experiments (ACE) Program is getting underway in the U. S. This program is being managed by the Electric Power Research Institute with contributions from a number of participants, including the USNRC. Objectives of the program are to:

* provide a comparative experimental basis for various filtration techniques;

* provide data for modeling the transport of radioiodine species;

* investigate fission product releases from core concrete interactions; and

* develop and validate computer codes.

The work of primary interest to filtered venting is that related to providing experimental data for various filtration techniques. This work will be conducted at the Hanford Engineering Laboratory. The data are then to be used to compare the merits of several filter concepts. Specifically, efficiencies of the following filter concepts will be evaluated experimentally:

* dry sand/gravel beds;

* deep pool scrubbers;

* submerged gravel scrubbers;

* combinations of pools and gravel scrubbers; and

* combined Venturi pools

The first phase of the work is to consist of 10 tests using five filter types at two water temperatures. Data on efficiency versus particle size will be collected. Aerosols of CsOH, CsI and MnO in a gas flow of about 0.1M^3/S with steam heating to simulate decay heat are to be used. The second phase consists of separate effects tests to evaluate the effects on filter efficiency of:

* pool depth;

* decay heat;

* the ratio of noncondensible gas to steam;

* volatile iodine species; and

* design specific parameters.

7. AREAS OF INCOMPLETE INFORMATION - There are a number of areas associated with venting for which incomplete technical information exists. These include the following:

a) A good quantification of the net reduction in core-melt probability (if any), its associated uncertainty, and how this might be expected to vary for different designs and operating characteristics. As examples, does venting result in an increase in core-melt probability for some risk significant accident sequences and, if so, which ones and how much? What reduction in core-melt probability can be expected for the Swedish FILTRA design at U. S. reactors?

b) A good quantification of the costs and benefits from venting (including any risks to be avoided) for each important accident sequence in a plant, and at various times within a sequence. This would include quantification of the reduction in accident consequences and net reduction in risk from venting based, in part, on a quantification of the reliability of important components such as rupture disks, and uncertainties in filtration performance.

c) A quantification of the risks of inadvertent or unnecessary venting. For example, what are the consequences of inadvertent or unnecessary venting and how would these vary for different meteorological conditions?

d) Identification and quantification of any negative impacts related to design changes on existing safety systems.

e) How well can existing designs survive accident conditions such as hydrogen combustion, and external challenges such as seismic events and tornados?

f) How should vent systems be actuated (actively, passively) for optimum safety and reliability? As examples, how should vent valves be powered during station blackout conditions? Is there adequate assurance that containment could be re-isolated once vent valves are opened?

g) What are the costs and benefits of mitigation strategies other than venting? For example, can more reliable containment sprays and ADS reduce or eliminate the need for filtered venting?

8. REGULATORY ISSUES - There are also a number of important regulatory issues related to filtered vents which are important for use in the U. S.:

a) Is there a net safety benefit to venting? If so, under what conditions?

b) What are the accident conditions and off-site environmental conditions where venting is justified? When is venting not justified?

c) What design, testing and quality assurance standards should be applied to vent systems that may be called upon only during accidents more severe than those generally considered to be within design bases?

d) How should vent systems be operated (passively or actively)? If actively operated, who should make the decision to vent and under what conditions?

e) What performance standards (degree of mitigation) should be applied to vent systems?

f) Should filtered venting be required in order to provide an adequate level of safety, or is it a safety improvement that is to be judged by cost-benefit analyses?

g) If the latter, how should the effects of land contamination be factored into any cost-benefit study?

h) If not required, what safety credit can be claimed in licensing and operational assessments?

9. SUMMARY - The capability to vent reactor containments in the U. S. currently exists through the use of existing systems. Unfortunately, during severe accidents the filters that are now in place would most likely be bypassed due to failed ductwork upstream, or would not be capable of trapping large quantities of aerosols. In BWRs with suppression pools, however, venting can be accomplished to take advantage of the excellent scrubbing of the pool water. For those reactors, venting during severe accidents could be called for and has been approved via Emergency Procedure Guidelines. The main purpose of venting as specified in the BWR EPGs is to prevent a catastrophic containment failure and uncontrolled release to the environment. Venting has also been shown to be potentially beneficial by preventing core damage caused by loss of reactor coolant system injection. An evaluation of venting in BWRs with Mark I containments has identified several negative aspects, not least of which is the possibility of unnecessary or inadvertent venting.

Programs are underway to better understand the issues related to containment performance. Risk evaluations of issues such as containment venting are being performed to evaluate the net impact on safety of proposed and considered hardware or operational improvements. Significant uncertainties are being addressed related to phenomenological, hardware, and procedural considerations; and key regulatory questions remain. Notwithstanding the uncertainties, venting is seen as potentially valuable in preserving the containment function in the event of a severe accident. It is the goal of research in the U. S. to quantify the benefits of venting, identify ways to minimize the negative aspects, and to help resolve related regulatory issues.

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11. REFERENCES

1. H. Lawroski, et al., Final Safety Analysis Report on the Zero Power Plutonium Reactor (ZPPR) Facility, Argonne National Laboratory, ANL-7471, June 1972.

2. J. L. Broderick, Final Design Report-FFTF Containment Margins, Hanford Engineering Development Laboratory, TC-1519, July 1981.

3. General Electric Company, BWR Owner's Group Emergency Procedure Guidelines, Revision 4, NEDO-31331, March 1987.

4. Bird, R. G., Boston Edison Company, Information Regarding Pilgrim Station Safety Enhancement Program, BECo ltr. 87-111 to S. A. Varga, US NRC, dated July 8,1987.

5. Vermont Yankee Nuclear Power Corporation, Vermont Yankee Containment Safety Study, report dated August 1986.

6. Hanson, D. J., et al., Containment Venting Analysis for the Peach Bottom Nuclear Power Plant, NUREG/CR-4696, EGG-2464, December 1986.

7. Amos, C. N., et al., Evaluation of Severe Accident Risks and the Potential for Risk Reduction: Peach Bottom, Unit 2, Draft NUREG/CR-4551 for comment, Volume 3, May 1987.

8. U. S. NRC Office of Nuclear Regulatory Research, Reactor Risk Reference Document, NUREG-1150 (Draft), February 1987.

9. Amos, C. N., et al., Containment Event Analysis for Postulated Severe Accidents: Peach Bottom Atomic Power Station, Unit 2, NUREG/CR-4700, Volume 3, May 1987.

10. U. S. NRC, Reactor Safety Study, WASH-1400 (NUREG-75/014); October, 1975.

TABLE 1. EFFECTS OF VARIOUS VENTING SYSTEMS ON ACCIDENT MITIGATION

Parameter vent system	Duct vent system	Hard pipe vent system with a rupture disk	Hard pipe vent system without a rupture disk	Hard pipe, filtered
Prevent loss of SRV control high containment pressure?	yes	yes	yes	yes on
Prevent early containment failure by:				
Overpressurization	yes	sometimes[a]	yes	yes
Liner melt-through?	no	no	no	no
Potentially adverse effect recovery equipment?	yes	no	no	no on
Prevent hydrogen burns in RB?	no[b]	sometimes[a]	yes[c]	yes[c]
Ability to reisolate?[d]	maybe	yes	yes	yes
Prevent inadvertent operation?	no	yes	no	no

Notes:

a. The generic system rupture disk was assumed to fail at 60 psig (0.5 MPa) for the qualitative study. Since the calculated station blackout containment pressures are below the containment design pressure prior to vessel failure, the vent will not operate early. Due to the high probability of early containment failure at vessel failure, the hydrogen may not be vented in station blackout sequences. Other sequences, such as TW and ATWS result in containment overpressure failure prior to vessel failure without venting. Consequently, early venting could save the containment from over-pressure failure and allow release of hydrogen prior to vessel failure.

b. The duct system is expected to fail at very low pressures (< 1 psid). Therefore venting through a duct system is expected to release into the reactor building.

c. When a hydrogen rich, but oxygen poor, containment atmosphere is vented to the atmosphere or reactor building, there is concern about possible combustion. However, it is suspected that the probability of combustion in a hard vent line is no greater than in the inerted primary containment. Combustion may occur after sufficient mixing occurs in the plant stack. A energenic combustion could rapidly sweep fission products into the environment and increase the source term.

d. The ability to isolate the containment after venting could lower the risk relative to a vent system which can not reisolate. It is assumed that the hard pipe systems (i) would be designed to operate without dependence on the normal AC power sources, (ii) would be designed to open and close under severe accident conditions, and (iii) would permit safe manual operation if all else fails. Conversely, the duct vent systems were assumed to have (i) valve placement close to the hard pipe/duct interface, (ii) only AC powered valve actuators, and (iii) valves which were not capable of opening and closing during some severe accident conditions.

TABLE II. RISK COMPARISONS OF STATION BLACKOUT SCENARIOS WITH VARIOUS VENTING SYSTEMS

	Qualitative Change in Risk Relative to a Non-venting Scenario							
			Hard pipe vent system				Hard pipe	
	Duct		with a		without a		filtered	
	vent system		rupture disk		rupture disk		vent system	
Accident end state	Early	Late	Early	Late	Early	Late	Early	Late
Vessel failure with early liner melt-through	n/c[a]	n/c	n/c[b]	n/c	n/c[a]	n/c	n/c[a]	n/c
Vessel failure with early containment overpressure failure	<	n/c	n/c[c]	n/c	<	n/c	<	n/c
Recovery w/o vessel or containment failure[d]	<	n/c	n/c[b]	n/c	>	n/c	>	n/c
Recovery w/ vessel failure and w/o containment failure[d]	>	>	>	>	>	>	>	>
Vessel failure and late drywell containment failure	<[e]	<	<	<	<[e]	<	<[e]	<

Legend:

- Early — Initiate venting prior to vessel failure and left open. (The rupture disk will not open until the vessel failure.)
- Late — Initiate venting after vessel failure.
- < — The venting scenario consequences are expected to be less than (<) the non-venting consequences
- > — The venting scenario consequences are expected to be greater than (>) the non-venting consequences
- n/c — No significant change in risk

Notes:

a. Preliminary review of the NUREG/CR-4551 results indicate little change in consequences if venting is initiated prior to early liner melt-through. Venting may reduce the pressure driving force for radionuclides from the drywell, thereby potentially increasing the overall containment DF.

b. The generic system rupture disk was assumed to fail at 60 psig for the qualitative study. Since the calculated short term station blackout containment pressures are below the containment design pressure prior to vessel failure, the vent will not operate early. It is assumed that the rupture disk will open upon vessel failure for early venting or late containment pressurization for the late venting case.

c. It was assumed that early venting with a rupture disk would not prevent early containment overpressurization failure at vessel failure. The containment pressure at vessel failure, the timing of early venting, and the vent path relief capacity during vessel failure must be evaluated to determine whether this assumption is valid. In addition, the pool DF should be evaluated during the high flow conditions at vessel failure.

d. For these scenarios, accident recovery was assumed to prevent containment failure. If the vent systems were opened under these circumstances, it was judged to increase risk since there would be an unnecessary release to the public since the accident did not lead to containment failure in the non-venting case. The hard pipe, filtered vent system is expected to minimize the consequences. However, it is not clear whether an elevated, hard pipe release through the plant stack would have lower consequences than a system which discharges into the reactor building.

e. The effectiveness of the filter system (either suppression pool or an external system) would determine whether there would be higher consequences. It is not clear whether an early scrubbed release will always compensate for a reduction of time for evacuation warning.