Technical Assessment
GSI-193, BWR ECCS Suction Concerns

Relevant Experiments and General Review of Selected Thermal-hydraulic Phenomenon Effecting the Ingress of Non-condensable Gases in the BWR ECCS System During a HELB Accident

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10/25/2005

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5/20/2010

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EXECUTIVE SUMMARY

This report is part of the technical assessment of the Generic Safety Issue (GSI) 193, “BWR ECCS Suction Concern.” This report is submitted to complete one of the milestone included in the task action plan to resolve this generic issue. The task action plan involves three phases. The first phase is subdivided in three sections. This report correspond to Part B of the first section, named: Pool dynamics. The Pool dynamic section has three parts.

The main objective of this report is to present the results of a literature review of relevant experiments and selected thermal-hydraulics phenomenom occurring during the blowdown phase of a high energy line break (HELB) in Boiling Water Reactors (BWRs).

The most significant experiment of study found, was performed by the Technical Research Centre of Finland (VTT) and Lappeenranta University of Technology (LTKK), in 2004. This experiments studied the potential of gas ingress into the ECCS system of a BWR Nuclear Power Plant (NPP), caused by an injection of a liquid-gas jet into the suppression pool. The model used for the study can be compared with a typical Mark-II BWR containment. The purpose of this experiment is related with the main objective of generic safety issue (GSI) 193, “BWR ECCS suctions concerns,” which is to assess the potential of BWR ECCS pump performance degradation as a result of non-condensable gas entering into the pumps suction path. In the experiment preformed by VTT and LTKK, 5% void fraction was detected in the ECCS pipe during duration of the blowdown process.

Separate tests on void fraction (VF) demonstrated that, from 100% to 75% design flow-rate, a single-stage pumps start to degrade at 3% VF and degraded considerably at 7% VF. Pump flow was not completely stop at this flow rate. For 33% to 17% design flow-rate the pump performance degraded at void fractions lower than 3% VF and collapsed completely at 7% VF. For the case of 7% VF the recovery-time of the pump was 30 seconds after the injection of air was suspended. In addition this experiment helped to understand and identify to types of jets occurring during the blowdown phase of a HELB. This two jets are (1) the liquid jet followed by a column of non-condensable gases and (2) the subsequent non-steady gas-jet. This two jets have been identified as (1) the primary sources of gas injected into the suppression pool, (2) the mechanism that break the large bubbles, and the (3) mechanism that induce a recirculation motion inside the suppression pool. In VTT-LTKK experiments, small bubbles were trap in this recirculation motion, increasing the potential of gas ingress into the ECCS system.

Similar experiments, on centrifugal pumps, were performed in the United States by Arizona Public Service (APS) for Palo Verde Nuclear Generating Station (PVNGS). NRC identified several uncertainties in these experiments, and incorporated them to estimate a change in core damage frequency of 5.7 x 10-6.

This report, also summarizes potential analytical tools to estimate the amount of gas in the suppression pool. These analytical tools and experiments results will be used in Part C of the Pool dynamics section of GSI-193 Task Action Plan Phase I.

1. INTRODUCTION

This report describes relevant experiments and theoretical analysis pool phenomena at a BWR suppression containment during a high energy line break (HELB) BWRs. Several phenomena occur at the same time during a blowdown process. These phenomena are affected by the geometry of the suppression pool, magnitude or severity of the accident, thermodynamics conditions at the time of the accident, and the response of the emergency core cooling system (ECCS). The amount of gas entering in the ECCS system depends of the combination of all this factors. This report presents experiments performed in suppression pools, and general thermal-hydraulics experiments and concepts of phenomena that increase or decrease the potential of gas ingress into the ECCS pump suction path.

The first section summarizes an experiment performed by the Technical Research Centre of Finland (VTT) and Lappeenranta University of Technology (LTKK) [Ref. 1]. This experiment quantifies the amount of gas entering into typical Mark-II NPP ECCS system and the effects it has on the ECCS pump performance. In addition this experiment describe the types of jets, which occur during the blowdown phase of a HELB. Those are (1) the liquid jet followed by a column of non-condensable gases and (2) the subsequent non-steady gas-jet. The first type of jet drives the initial motion of the fluid in the suppression pool. The second type provides the main sources of non-condensable gases with the potential to enter into the ECCS system and a secondary force that superimposed over the initial motion of the fluid.

The following two sections summarize experiments and analytical tools to estimate the size of bubbles generated by liquid jets and by vortex also induced by the liquid jets.

The last two section present experiments of two-phase counter-flow through perforated plates and introduces the two non-dimensional numbers proposed to describe the deformation of gas bubbles at the ECCS strainer surface.

2. SUPPRESSION POOL EXPERIMENTS

2.1 VTT-LTKK blowdown experiment

In 2002, the Technical Research Centre of Finland (VTT) and Lappeenranta University of Technology (LTKK), conducted experiments to study the effects of injection of non-condensable gases (air) into a typical Mark-II Nuclear Power Plant (NPP) condensation-pool. The main objective of these experiments was to study the possibility of gas ingress into the ECCS system during the blowdown phase of a HELB. In addition, studies were performed on the effect of non-condensable gases entering into a single-stage centrifugal pump, by injecting gas directly into the up-stream of the ECCS pump [Ref. 1, and 2]. Units are presented in SI followed by English units in parentheses.

The experimental facilities were design to simulate one-forth scale of the Mark-II NPP condensation pool (suppression pool). The location of the vents (downcomers) and strainers in the Mark-II plant can be compare with a BWR Mark-II suppression containment. The downcomers in the Mark-II NPP has a diameter of 0.6 meter (1.96 foot) and are located 6.4 meters (21 foot) below the suppression pool water-level. The penetration of the strainer suction-pipe is at the vertical wall of the containment at 5.8 meters (19 foot) below water-level. The strainer has a form of a box with perforations of 4 millimeters diameter. The total area of the strainer is 32 m^2 (344.4 ft^2) with a total hole are of 8.4 m^2 (90.4 ft^2). The density is 20,889 holes per square meter. Figure1 presents the general configuration of the experimental facilities of the VTT-LTKK condensation pool experiments.

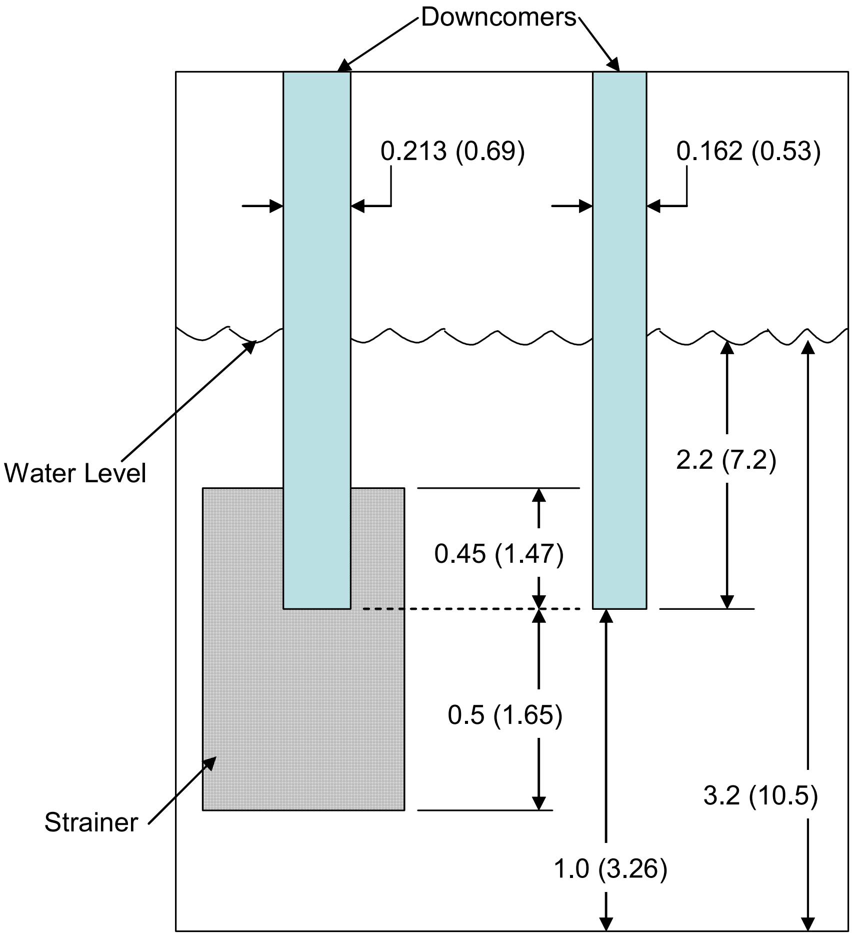

Figure 1. VTT-LTKK Condensation pool experimental facilities; *meters (foots)*

For experimental purpose it is assumed that the low pressure pump is drawing water from a single strainer at a minimum mass-flow rate of 25 kg/s (396 gpm, STD H_2O) at the same time the containment spray pumps are drawing at full capacity of 75 kg/s (1188.7 gpm, STD H_2O), from the same strainer, for a total of 100 kg/s (1585 gpm, STD H_2O) of mass-flow rate per strainer.

The physical model used for the experiment has two blowdown-pipes with 0.162 (0.53 foot) and 0.213 (0.69 Foot) meters in diameter and a submergence of 2.2 meters (7.2 foot)). The water level in the suppression pool is 3.2 meters (10.49 foot).

The volumetric flow-rate and initial velocity of the jet used in the experimental facilities to simulate the Mark-II NPP blowdown is about 0.14 m^3/s (4.94 ft^3/s)and over 40 m/s respectively (131.2 foot). The set of blowdown experiments where done for three cases. The first case was without strainer and without pump, the second with strainer and without pump, and the third with strainer and pump. A fourth series of test were done with the pumps running separately.

For the first series of tests, two types of jet were without the stainer neither the pump. One jet had the downcomer partially filled with water and the other jet had the downcomer clear of water. The water level inside the partially-filled downcomer corresponds to the water level of the suppression pool. This two jets exhibited different behaviors. In the partially-filled case, the following column of air hit the bottom of the pool and broke-up into small bubbles. The observed jet, hitting the bottom of the pool, reached a maximum diameter of 0.9 meter (2.95 foot) which is 4.2 times wider than the downcomer diameter. Two seconds after the initial blowdown, the presence of small bubbles obstructed the sight into the suppression pool. After 15 seconds, the amount of bubbles reduced to a level were it was possible to observed the downcomer again.

On the other hand, in the case of a gas-jet with a cleared downcomer, the initial jet did not touch the floor. The jet was rather symmetrical and formed a bubble of approximately 0.9 meter, which is similar to the diameter of the jet for the partially-filled case. In this two cases just one pipe was injected air for 19 seconds. In some of the tests with two downcomers, air was injecting for approximately 9 seconds. In those cases the present of small bubbles, going downwards, were observed after 10 seconds.

The second series of tests were done with the presence of a strainer in the suppression pool. For this test, a camera was installed inside of the strainer to analyze the possibility of gas ingress into the strainer. During all the tests the strainer was surrounded by air bubbles for more than 30 seconds, at the time air bubbles were observed inside strainer.

The third series of tests were done with the presence of a strainer and the ECCS pump drawing water from the suppression pool at a constant mass-flow rate of 100 kg/s (1585 gpm, STD H_2O) since the beginning of the blowdown. Air was injected for 20 seconds. Air bubbles were observed into the suction pipe for the 20 seconds of blowdown when the air was injected through the two downcomer pipes. A rough calculation estimate 5% of void fraction. The pump head and the volumetric flow did not degraded at that void fraction.

The fourth series of tests were done to the pump running separately. The pump was exposed to void fractions higher than 7%. For water flow rates of 75 kg/s (1188 gpm, STD H_2O) and 57 kg/s (903 gpm, STD H_2O) the pumps start to degrade at 3% and degraded considerably at 7%. The pumps did not collapsed completely at this flow rates. For water flow rates of 25 kg/s (396 gpm, STD H_2O) and 12.5 kg/s (198 gpm, STD H_2O) the pump performance degraded at void fractions lower than 3% and collapsed completely at 7%. For the case of 12.5 kg/s

(198 gpm, STD H_2O) the recovery-time of the pump was 30 seconds after the injection of air was suspended.

From this experiment VTT concluded that the gas entered into the ECCS system of Mark-II NPP during a HELB is small enough to not challenge the operability of the ECCS pumps. Similar tests, on Pressurized Water Reactors (PWR) ECCS pumps, were performed by Arizona Public Service (APS) Company in United States on 2004. The next section summarize the results of this tests and the uncertainties involved with the methodology.

2.2 Palo-Verde experiments

On July 2004, Arizona Public Service (APS) discovered that a significant section of the containment sump safety-injection-piping at all three Palo Verde Nuclear Generating Stations (PVNGS) were voided with gas [Ref. 3].

APS performed a series of tests to analyze the transport of this void inside the ECCS pipe of PVNGS and to analyze the impact of this void on ECCS pump performance. Several scenarios of void-fraction versus time were defined from the one-eight scale transport-tests. Multi-stage and single-stage were tested for these scenarios.

Although these tests provided a useful insight of the pump performance, NRC identified uncertainties on the tests methodology that could have an impact in the overall conclusions regarding the availability of the ECCS pumps following a loss-of-coolant-accident (LOCA). After accounting for these uncertainties, NRC estimated a change in core damage frequency of 5.7×10^{-6}.

2.3 GESSAR (General Electric Proprietary Information)

A significant amount of experiments were performed in the 1970s by General Electric to analyze the hydrodynamics loads, caused by the blowdown forces over the structure and components of BWR suppression pools. These experiments were documented in the General Electric Standard Safety Analysis Reports (GESSARs). These experiments studied liquid-gas to understand and quantify the hydrodynamics loads caused by the initial blowdown of a BWR, but not the potential of gas ingress into the ECCS system. In addition these experiments did not incorporate the strainers, neither the effect of gas ingress to the ECCS pumps performance [Ref. 4, 5, 6, and 7].

3. LIQUID JETS

Some experiments has been done to estimate the size and behavior of the bubbles formed during the initial gas injection in BWRs [Ref. 8]. But most of these experiments did not incorporated bubble break-up, neither the influence of the initial liquid clearance from the pipe. The initial clearance of the partially submerge downcomer induces a liquid jet, which force has been observed to break bubbles and create a recirculation motion [Ref. 1 and 2].

In experiments, described in previous sections, was observed that this initial liquid-jet has the potential to pull the gas bubbles to the bottom of the pool and break it in very small bubbles. Literature about this specific phenomena was not found, but literature of a similar phenomena was found. This similar phenomena is liquid-jets plunging over free water surface.

A substantial amount of experiments have been done in the area of gas-entrainment caused by plunging liquid-jets, which force and potential to break bubbles can be compare with forces of a submerge liquid jet.

This information is important to estimate the amount of non-condensable gases in a BWR suppression pool during the evolution of a HELB. The following two section summarizes some of the theories and experiments of plunging liquid jets.

3.1 Gas entrainment caused by plunging liquid-jets

The literature presented in this section study the formation, break-up, and size distribution of bubble in plunging liquid-jets. This section begins with a review of a study, where preliminary assumptions of the behavior of submerged jets were done, and discuss some limitations of those assumptions. The rest of this section presents experimental and theoretical studies that can be used to analyze the liquid-gas jet phenomena during the blowdown phase in BWR

In 1977, J.F. Moody performed a review of submerged liquid-jets in BWR suppression pools [Ref. 9] . Based on Helmholtz instability and turbulent layer characteristics, Moody determined that shear forces and pressure gradients are negligible. Through observation and analytical model, Moody concluded that a submerged liquid-jet at high velocities can penetrate long distances without significant spreading. Moody concluded that shear forces and pressure gradients are negligible. This assumption is useful for liquid jet alone. When non-condensable gases are incorporated in the analysis, the interfacial shear stress should to be consider. That is the case when the liquid is ejected completely out of the downcomer, into the suppression pool, follow by a bubble of non-condensable gases during. which is the phenomena analyzed in GSI-193. As previously mentioned, this phenomena can be compare with plunging liquid jets.

The plunging jets are column of liquid injected to a free water surface. The edge of the cylinder-jet induces a strong shear force. This shear force causes the gas around the jet to enter into the liquid pool [Ref. 10]. In BWRs the jet of liquid is injected though a submerged pipe and followed by a bubble of non-condensable gases. Although this two scenarios are different, we can establish an analogy between the shear forces that non-condensable gases experience at the edge of the pluning liquid-jet and shear forces experienced by non-condensable gases in the submerged liquid jet in a BWR suppression pool during a HELB.

One of the most typical non-dimensional numbers, used in the following experiments to estimate the maximum size of stable bubbles in a viscous flow, is the Weber number. The Weber number (Equation-1) establish the ratio of inertia to surface-tension a bubble experiences in a viscous flow [Ref. 11].

$$We = \frac{\rho_l V^2 d}{\sigma} \qquad \text{Equation-1}$$

Where
$\boldsymbol{D}_l$ = liquid density,
V = fluid velocity,
d = bubble diameter, and
$\boldsymbol{F}$ = interfacial surface tension.

Researchers from the University of New Castle, Australia, performed experiments of plunging jets over free surface water [Ref 10]. They found that with a Weber number of 1.2, the maximum size of the bubbles can be predicted within 20% of the measured values. They assumed that, for this set of experiments, the eddies responsible of breaking the bubbles are isotropic and the bubbles lies within the inertial sub-range of the Kolmogoroff scale. In this case the bubbles would be small, compared to the turbulent macroscale; and large compare to the turbulent microscale. The kinetic energy would be independent of viscosity, and the velocity can be defined in terms of energy dissipation rate (Equation-2).

$$V^2 = 2.0\left(\frac{\varepsilon d}{\rho}\right) \qquad \text{Equation-2}$$

Where
$\boldsymbol{g}$ = energy-dissipation-rate per unit volume.

The energy dissipation rate was calculated from the energy balance across the mixing zone volume; following the analysis of Cunningham (1974) for a liquid jet gas pump. After simplification and adaptation of the energy balance equation, the expression for the energy dissipation-rate yield:

$$\varepsilon \approx \frac{\rho u_j^{\,3}}{2L}\left[b - 2b^2 - b^3\left(1+\lambda_1\right)^2 + 2b^3\left(1+\lambda_1\right)\right] \qquad \text{Equation-3}$$

Where
L = mixing length,
u_j = liquid jet velocity,
b = jet/column area ratio, and
8_1 = inlet gas/liquid volumetric flow ratio.

The diameter of liquid jets used for the experiment were 44, 74, and 95 millimeters (1.73, 2.91, and 3.74 inches). The average velocity was 11.5 m/s (37.73 ft/s). The liquid and gas used were water and air at standard atmospheric conditions. The mixing length was between the range of 0.07 (0.23 foot) and 0.25 meters (0.82 foot) . The sizes of bubble observed in this experiment were from 0.22 (0.0086 inch) to 0.72 millimeters (0.028 inch). The size distribution was fitted by a log-probability relationship, and the ratio of the Sauter mean diameter to the maximum measured bubble size was equal to 0.61. The average void fraction in the mixing zone was around 11%.

Similar experiments were conducted by Rensselaer Polytechnic Institute (RPI), New York, in 1993, for two type of liquid plunging jets [Ref. 12]. The two type of jets were smooth and turbulent jets. The mean velocity of both jets were about 5 m/s (16.4 ft/s); and with an initial diameter of 5 millimeters (0.19 inch). The smooth jet produces bubbles within the range of 0.015 (0.00059 inch) and 0.3 millimeters (0.0118 inch) in diameter. On the other hand. The turbulent jet generated bubbles with diameters within the range of 1.0 (0.039 inc) and 3.0 millimeters (0.118 inch). It was found that the buoyancy force for bubbles with diameters less than 0.02 millimeters (0.00078 inch), is almost negligible. This bubbles traveled at same velocity and direction of the flow. For the turbulence jet, it was observed void fractions over 20% in the mixing zone. In addition, it was observed that the void fraction increases with the increase in turbulence. The turbulence in jet was increased by adding internals inside the liquid-jet nozzle outlet and increasing the distance between the outlet and the water surface. This work establishes a significant difference between the bubble sizes generated by laminar (smooth) jet and turbulent (rough) jets.

In previous investigations, the group of scientists from Australia, used acoustic techniques to estimate the distribution of bubble sizes produced by plunging jets [Ref. 13]. The experimental facilities used a nozzle of 0.025 meters (0.082 foot) diameter. The jet distance from the water surface and velocity was varied to analyze their impact in bubble sizes. It was found that for velocities between 2.3 (7.54 ft/s) and 4.4 m/s (14.4 ft/s) the amount of gas entrained differs but not the size distribution, for which the most abundant size of bubbles in the experiments was 1 mm (0.039 inches). The population of larger bubbles diminishes logarithmically and the amount of bubbles smaller than 1mm (0.039 inches) was very small. This work corroborate the range of bubbles size found by (RPI) in turbulent jets. In addition it provide useful information to estimate a distribution of bubbles sizes.

Most of this experiments were performed at relative small scales. General considerations and ranges of applicability should be establish for future analysis using this information. Further investigations demonstrated the effects that model scales has in the air entrainment of liquid plunging jets [Ref. 14]. It was found that model studies with Weber number lower than 1000 will underestimate air entrainment when prototypes flow has weber numbers greater than 1000.

In addition to the liquid jet, the recirculation motions presents in the suppression pool can generate shear forces that can break-up bubbles injected after the initial liquid jet. The next section summarizes some experiments performed to estimate the size and distribution of bubbles inside an irotational vortex.

4. POOL DYNAMICS - VORTEX

In addition of generating a strong interfacial shear force, it was observed that the initial liquid-jet induces a recirculation motion in BWRs suppression pools [Ref. 1 and 2]. Although this recirculation motion (vortex) dissipates with time, its been observed in previous experiments that it induces strong downward motions, capable to capture small bubbles in its main stream. This recirculation motion can be compare with a Hills' vortex [Ref. 15].

An interdisciplinary group of scientists conducted experiments to analyze the bubble break-up and estimate the size of bubbles in a Hills' vortex [Ref. 16]. They proposed the following equation to estimate maximum stable bubble radius:

$$\left(r_b\right)_{\max} = \sqrt[3]{\left(\frac{We_c\sigma\left(R-\delta\right)^4}{128\rho\left(K\left(U_0\right)_{l=L}\right)^2}\right)}\,\frac{1}{r^2} \qquad \text{Equation-4}$$

Where:
We_c = critical Weber number,
F = interfacial surface tension,
R = vortex radius,
* = jet thickness,
r = radius from the center of the vortex stagnation point to the wall,
K = proportionality constant (0.38), and
U_o = jet velocity.

Although 1.2 is a general accepted value for the Weber number, they found that for this specific phenomena a value of 4.7 is more suitable. This study indicated that the value of 1.2 is based on an energy dissipation rate and 4.7 is based on velocity profile, which is used in this experiment.

Equation-4 provides a potential tool to estimate the continuos break-up of bubbles exposed to a steady liquid jet. The liquid jet and following the liquid-gas jet in BWRs are unsteady during a blowdown process. In addition, the upward motion of the bubbles will superimpose over the initial recirculation motion and eventually dominate the dynamics of the suppression pool. By that time, the assumption of a Hills' vortex might not be appropriate to define the dynamics of the suppression pool. Also, scale effects should be consider all the time for any calculation. Saying that, we can predict that several assumptions and bounding conditions has to be establish in order to make a rough estimation of the inventory of gas in the suppression pool and the size distribution of the bubbles.

The size of the bubbles determines the potential transport of this bubbles into the surface of the strainer, trespass the strainer, and eventually entering into the ECCS pipe. The following section summarizes some experiments of two-phase flow through perforated plates and analytical tools to analyze bubble deformation.

5. TWO PHASE FLOW THROUGH PERFORATED PLATES

During the blowdown process the strainer could be exposed to three different two-phase flow fields. The first one is the two-phase jet, the second is the exposure of the strainer to the envelope of the following gas-bubbles, and the third is the bubbly flow through perforated plate. The phenomena of bubbly flow through perforated plate could be observed from the bubbles that mixes in the suppression pool water.

From some experiments, performed to understand the impact of underwater high energy line breaks , it was observed that two phase flows over 16 m/s (52.5 ft/s) are extremely violent and have a potential to make gas to go through perforations. In this experiment the perforation were too big (100 mm); compared to the typical perforation of the BWR ECCS strainers (3.175 mm, 0.125 inches).

Another experiments have been performed to estimate the countercurrent flow limitation of gas and liquid [Ref.17]. In these experiments gas and liquid, divided by a perforated plate, flow in different directions influenced by gravity. Further experiments included a jet at the top of the perforated plate [Ref. 18]. This experiments where done to analyze the limitation of liquid-jets to penetrate a perforated plate and cool a reactor vessel when steam was flowing against the liquid-jet direction.

In these experiments gas was injected at the bottom of the plate and water at the top. These phenomena can be related just with the second type of two-phase flow that ECCS strainers could experience during a blowdown process. When the envelope of a gas bubble enters in the strainer a certain volume of gas gets trap inside the strainer. We observed in these experiments that this gas exits the strainer very easily, which is similar to the case inside of a strainer when no suction forces are present. If the ECCS pumps initiates while gas still in the strainer, gas could be drawn into the ECCS pipe. This amount of gas is summed to the amount of bubbles in the suppression pool that might reach the strainer and flow through the strainer. Once the bubbles reach the strainer, it has to break and/or deform to pass through the strainer perforations. The following section presents a potential approach to analyze the deformation of bubbles.

6. BUBBLE DEFORMATION

The bubbles in the suppression pool can be driven to the strainer by the recirculation force inside the pool and by the suction force generated by the ECCS pumps. We can assume that bubbles of the same or lower diameter than the perforations of the ECCS strainer (3.175 mm, 0.125 inches) can flow in and out the strainer without significant resistance. Bubbles of bigger diameter have to deform or break to flow through the strainer. The tendency of a bubble to deform can be evaluated using the Eövtös (Equation 5) and Morton (Equation 6) numbers [Ref. 19].

$$E_o = \frac{\left(\rho_l - \rho_g\right) d^2 g}{\sigma} \qquad \text{Equation-5}$$

$$M = \frac{\left(\rho_l - \rho_g\right) \mu_l^4 g}{\rho_l^2 \sigma^3} \qquad \text{Equation-6}$$

Where
$\boldsymbol{D}_g$ = gas density,
$:_l$ = dynamics viscosity, and
g = gravity constant.

The tendency that a rising bubble has to deform decreases as the Morton numbers increases. An aspect ratio of a bubble between 0.8 and 1 has been suggested for a range of 1 to 10 Eövtös number and 1 to 10^{-6} Morton number [Ref. 19]. This range can be define as the spherical range of bubbles in viscous flows.

7. GAS BUBBLE TERMINAL VELOCITIES

Gas bubbles tend to rise because of the buoyancy force. Several experiments (including the one represented in Figure 2) have characterized the terminal velocities of various gas bubble sizes in both distilled and contaminated water (water with surfactant) [Ref. 20]. This experiment was conducted in settled water at an average water temperature of 20 °C.

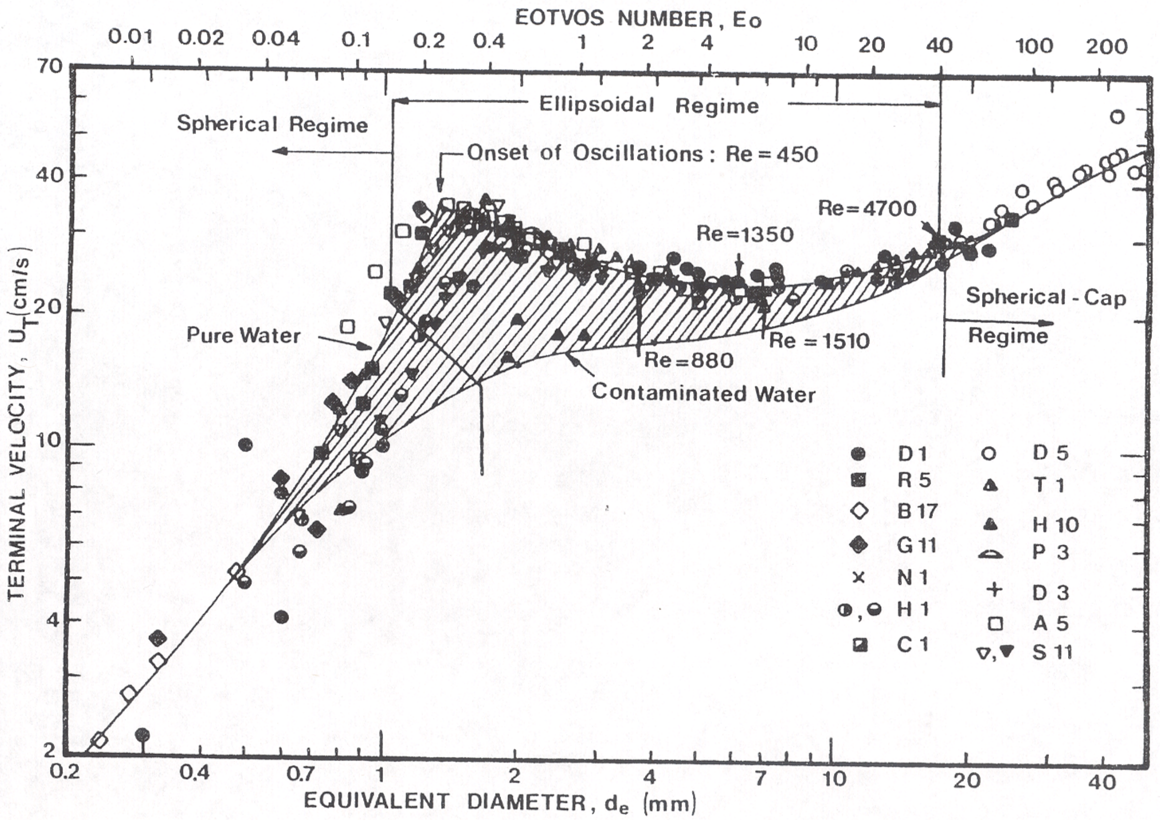

Figure 2. Terminal Velocity of Bubbles in Settled Water at 20 Degrees Celsius.

For further analysis of GSI-193, the terminal velocities of bubbles can compared with the velocity fields induced by the ECCS suction force and the recirculation in the suppression pool. This comparison could be used as a baseline to understand how does buoyancy forces compete against the fluid dynamics forces in the suppression pool.

8. SUMMARY

The most significant experiment included in this summary is an experiment performed by the Technical Research Centre of Finland (VTT) and Lappeenranta University of Technology (LTKK), in 2004. These experiments studied the potential of gas ingress, into the ECCS system of the a typical BWR Mark-II Nuclear Power Plant (NPP), caused by an injection of a liquid-gas jet into the suppression pool. The model used for the experiments can be compared with a typical Mark-II BWR containment. The purpose of this experiment is related with the main objective of generic safety issue (GSI) 193, "BWR ECCS suctions concerns," which is to estimate the amount of gas that could enter into the BWR-ECCS system during a HELB and the effects on the ECCS pump. In this experiment 5% void fraction was detected in the ECCS pipe through the blowdown process.

Separate tests on single-stage pump performance demonstrated for water flow rates of 75 kg/s (1188 gpm, STD H_2O) and 57 kg/s (903 gpm, STD H_2O) the pumps start to degrade at 3% and degraded considerably at 7%. The pumps did not collapsed completely at this flow rates. For water flow rates of 25 kg/s (396 gpm, STD H_2O) and 12.5 kg/s (198 gpm, STD H_2O) the pump performance degraded at void fractions lower than 3% and collapsed completely at 7%. For the case of 12.5 kg/s (198 gpm, STD H_2O) the recovery-time of the pump was 30 seconds after the injection of air was suspended.

From this experiment VTT concluded that the gas entered into the ECCS system of the during a HELB is small enough to not challenge the operability of the ECCS pumps. Similar tests, on Pressurized Water Reactors (PWR) ECCS pumps, were performed by Arizona Public Service (APS) Company in United States on 2004. The next section summarize the results of this tests and the uncertainties involved with the methodology.

Analytical tools, to estimate the size and distribution of the bubbles, have been suggested in this literature review for the blowdown phase of a HELB in the BWR suppression pools.

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