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SYSTEMS ANALYSIS-EXPERIMENT SPECIFICATION

CRITIQUE OF THE GENERAL ELECTRIC SAFETY-RELIEF VALVE DISCHARGE ANALYTICAL MODELS

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PROPRIETARY INFORMATION

I. INTRODUCTION

The General Electric document NEDE-20942-P[1] presents analytical models which are used to describe the safety-relief valve discharge phenomena and to predict the corresponding dynamic loads on the structures of the pressure-suppression pool. These models have been examined carefully and the results of this examination are given in this report.

Basically, the examination of these models proceeded in the following manner:

1) To determine the assumptions made, which include those clearly stated and those made implicitly;
2) To evaluate the validity and conservatism of those assumptions made, whenever it is possible;
3) To make sure the basic logic is followed in all the arguments: and
4) To fill the gaps of the arguments, if they do occur, whenever it is possible.

It is thought that this approach insures an objective, thorough, and even helpful critique.

The essential conclusion of this critique can be summarized as: the pipe clearing transient model and the pool response model are judged acceptable if the concerns expressed are satisfied; the bubble dynamics model and the model for the translational motion of the bubble are judged unreliable. Details upon which the judgements are made are presented in the body of the report.

Finally, for emphasis all the important questions raised and concerns found are underlined.

II. ANALYTICAL MODELS

1. PIPE CLEARING TRANSIENT

1.1 Assumptions

The basic assumptions of the pipe clearing model (listed on page 6 of NEDE-20942-P), with one exception, are acceptable. It should be pointed out that the validity of the final assumption which governs the history of mass flow rate of steam is not clear. In view of the fact that the time scale involved in valve actuation is comparable to that of the whole pipe clearing process, it is likely that a slight deviation of the mass flow rate-time relation from the assumed linear relation in the period of valve actuation will cause a substantial change of the distribution time-history of fluid properties inside the pipe. If this is indeed the case, the validity of this particular assumption is in doubt. It is this reviewer's opinion that a reasonable argument should be given to justify this particular assumption.

1.2 Equations of Motion

Equations (1) - (5) of Section 3.1.2 are immediate results of the basic assumptions and are judged acceptable if the cross sectional area of pipe is constant.

1.3 Initial Conditions, Boundary Conditions, and Solutions

All the initial conditions and boundary conditions given in Sections 3.1.3 and 3.1.4 are all natural results of basic assumptions and physical reality. The solution scheme described in Section 3.1.5 is also considered adequate.

2. BUBBLE DYNAMICS

2.1 Assumptions

A basic assumption of the model dealing with the dynamic behavior of an oscillating bubble, although it is not given explicitly in Section 3.2.1 of NEDE-20942-P, is that the size of the bubble must be small compared with the distance between the center of the bubble and any point on the boundary of the pool or surface of another bubble. The validity of this assumption, obviously, is essential for the survival of the first four assumptions given in Section 3.2.1. In other words, this particular model should not be applied to the situation in which the above mentioned assumption is seriously violated unless a convincing argument can be given to show that the calculation based on this assumption will give a fairly correct or a conservative estimate of dynamic loads on different parts of a structure.

Because of the importance of this particular assumption, it is suggested that a reasonable evaluation of its validity and the effect of deviation from it be provided by the vendor. It will be seen in later discussions that this task is indeed very complicated.

If the above mentioned assumption is not seriously violated, then the second through the fourth assumptions listed in Section 3.2.1 are acceptable. As for the first assumption, except in the bubble forming period, it is also valid. The effect of the deviation from this assumption in the bubble forming period is considered minor.

Another important assumption of this bubble dynamic model, unfortunately never mentioned any place in NEDE-20942-P, is that the bubble is treated as an adiabatic thermodynamic equilibrium system. This assumption will be evaluated in the following discussion.

2.2 Equations of Motion

Equations (21) and (22) are natural results of the spherical geometry assumption. Equation (23) is correct if we consider E_b as total stored energy (which includes kinetic energy and internal energy) of the bubble. (In this report, contrary to NEDE-20942-P, any quantity related to the bubble will always be denoted by a subscript "b".) Although Equation (23) is correct, the proper application of it is very difficult due to the fact that an empirical factor η is involved. Unless this factor can be calculated by another independent formula, it seems that a proper application of this equation is impossible. As a matter of fact, by suitably adjusting this factor, it is not too difficult to make prediction values fit those experimental data and thus conceal the weakness of other assumptions. It is suggested that an independent correlation be developed for predicting the empirical factor η.

On page 15 of NEDE-20942-P, E_b is given by

$$E_b = M_b e_b = \frac{1}{K-1} \frac{P_b}{\rho_b} M_b = \frac{P_b V_b}{K-1}$$

where

E_b = total internal energy of the bubble

M_b = total mass of the bubble

e_b = specific internal energy of the bubble

P_b = pressure of the bubble

ρ_b = density of the bubble

V_b = volume of the bubble

K = ratio of specific heat

according to nomenclature of NEDE-20942-P. From this expression and the

definition of related quantities, it appears that:

(1) Change of total bubble kinetic energy is not considered in energy Equation (23) of NEDE-20942-P,

(2) Fluid properties P_b, ρ_b, and e_b of the bubble are position independent, and

(3) The equation of state of fluid particles is adiabatic.

Apparently, Assumption (3) is reasonable. Assumptions (1) and (2), for this explosive bubble dynamic process, seem to deserve further evaluation. An estimate, using Raleigh's equation, indicates the validity of these two assumptions is indeed assured if

(i) $\frac{\rho_b}{\rho_L} \ll 1$ when $P_b \gg P_\infty$ and

(ii) Bubble temperature is not too close to absolute zero temperature when $P_b \ll P_\infty$

[ρ_L=water density, P_∞= hydrostatic pressure at the center of the bubble]

<u>These conditions apparently are satisfied for the current situation and Assumptions (1) - (3) are considered valid</u>.

Other equations in Section 3.2.2 of NEDE-20942-P are judged acceptable.

2.3 Initial Conditions

All the initial conditions listed in Sec. 3.2.3 of NEDE-20942-P are judged adequate if the bubble is formed at the tip of the ram's head. However, as Sec. 4.1 of NEDE-20942-P indicates, it is now assumed that the bubble is formed at a point approximately four (4) feet from the exit of the ram's head. Due to this change of location of bubble formation, it is extremely unrealistic to assume the same initial conditions (i.e., the initial bubble

radius is the same as the inside radius of the ram's head; the initial bubble expansion rate is equal to the water withdraw rate; and the initial bubble pressure is equal to that at the exit of the ram's head) as given in Sec. 3.2.3 of NEDE-20942-P. As a matter of fact, the true initial conditions of bubble dynamics are expected to deviate substantially from those listed in Sec. 3.2.3 of NEDE-20942-P if the bubble is formed several feet away from the ram's head.

The reason why it is now assumed that the bubble is formed four (4) feet from the exit of the ram's head, as explained in Sec. 4.1 of NEDE-20942-P, is that this adjustment will remove the apparent discrepancy with the measured data. In the same section, there is no mention of the adjustment of the bubble initial conditions. If the adjustment of the bubble formation position is not accompanied by that of the bubble initial conditions as suspected, then the adjustment of the bubble formation position alone can not be considered as a proper way to remove the apparent discrepancy and bring predicted values closer to the measured values.

Sec. 3.2.3 of NEDE-20942-P also claims that $P_2 = \frac{1}{2}P_1$ and $\rho_2 = \frac{1}{2}\rho_1$ (P_1, P_2, ρ_1 and ρ_2 are explained in Figure 5(b) of the same report). Because these relations violate the adiabatic relation P/ρ^k = constant, it is concluded that there must be a flow discontinuity (shock) in the region between the pipe exit and the ram's head. If shock does occur, its effects should be addressed. If shock does not occur, then the relations $P_2 = \frac{1}{2}P_1$ and $\rho_2 = \frac{1}{2}\rho_1$ are of concern and the assumptions which lead to these relations must be reevaluated.

3. POOL RESPONSE

3.1 Raleigh Bubble in an Infinite Pool

The presentation of the pool response analytical model as given in NEDE-20942-P is not well organized logically. As a matter of fact, certain important assumptions are not clearly stated and certain key conclusions are drawn without reasonable argument.

In order to get a clearer picture about this model, the mathematical formulation presented in NEDE-20942-P is revised and given as follows (Nomenclature is identical to that in NEDE-20942-P):

Conservation of Mass (in spherical geometry):

$$\frac{\partial V}{\partial r} + \frac{2}{r} V = 0 \qquad (3\text{-}1)$$

Conservation of Momentum (in spherical geometry)

$$\frac{\partial V}{\partial t} + V \frac{\partial V}{\partial r} = - \frac{g_c}{\rho_L} \frac{\partial P}{\partial r} \qquad (3\text{-}2)$$

The solution of Equation (3-1) is

$$V = \frac{Q(t)}{4 \pi r^2} \qquad (3\text{-}3)$$

where Q (t) is a certain function of time. If the velocity field given in Equation (3-3) represents the velocity field outside (and on) the bubble, then on the bubble surface $r = R_b$, $V = \dot{R}_b$. In other words,

$$Q(t) = 4\pi R_b^2 \dot{R}_b \qquad (3\text{-}4)$$

Equations (3-3) and (3-4) now imply that

$$V = \left(\frac{R_b}{r}\right)^2 \dot{R}_b \qquad (3\text{-}5)$$

With the help of Equation (3-3), integration of Equation (3-2) leads to

$$P - P_\infty = \frac{P_L}{g_c} \left[\frac{\dot{Q}(t)}{4\pi r} - \frac{(Q(t))^2}{32\pi^2 r^4} \right] \tag{3-6}$$

Thus, in general, the pressure field is neither a harmonic function nor a potential field (which contradicts repeated statements in Section 3.3.3 and Appendix C of NEDE-20942-P). The reason it is not is that, as indicated in Equation (3-2), the gradient of the pressure field is not a linear function of the velocity field. It is exactly this same reason that the image method generally can not be used to satisy the free surface (constant pressure) boundary condition. Only in the case where the stream term (which is not linear in velocity, and for spherical geometry is $V \frac{\partial V}{\partial r}$ only) can be neglected will the pressure field be represented by the harmonic function and the image method can be applied to satisfy the free surface boundary condition.

Another insight which can be drawn from Equation (3-6) is that for any point far away from the center of a spherical flow field, the strength of the pressure is largely determined by the term which varies as $\frac{1}{r}$. In other words, $\dot{Q}(t)$, the second time-derivative of bubble volume, is decisive in determining the pressure strength in the region where $r >> R_b$ if the flow field is spherically symmetric.

With the understanding of the roles played by $\dot{Q}(t)$ and $Q(t)$ in determining the pressure field, a further evaluation of the bubble dynamic model is now possible. Because we are interested in the pressure field around the pool wall where $r >> R_b$ is assumed (if this is not the case, the analytical models of bubble dynamics and pool response are no longer useful), the accurate prediction of $\dot{Q}(t)$ is far more important than that of $Q(t)$. It appears that the presence of the pool wall and pool free surface

will make the prediction of $\dot{Q}(t)$ **non-conservative** and overconservative respectively. It also appears that the opposite holds true for the prediction of Q(t). Because $\dot{Q}(t)$ plays a far more important role than Q(t) in the determination of the pressure field around the walls, our observation is that the prediction based on this particular bubble model is non-conservative in the case where the bubble is closer to the wall than the free surface and overconservative in the case where the bubble is closer to the free surface than to the wall. Futhermore, since the suppression pool is mostly surrounded by walls, the conclusion is that, generally, this bubble dynamics model is non-conservative in its usefulness for predicting the pressure load on the pool walls.

In view of Equation (3-4), it is seen that

$$\dot{Q}(t) = 4\pi R_b^2 \ddot{R}_b + 8\pi R_b \dot{R}_b^2 \tag{3-7}$$

Upon combining Equations (3-4), (3-6) and (3-7), we have

$$P - P_\infty = \frac{\rho_L}{g_c}\left[\frac{R_b^2}{r} \ddot{R}_b + 2 \frac{R_b}{r} \dot{R}_b^2 - \frac{R_b^4}{2r^4} \dot{R}_b^2\right] \tag{3-8}$$

Let $r = R_b$ and $P = P_b$, Equation (3-8) reduces to Raleigh's equation, i.e.,

$$P_b - P_\infty = \frac{\rho_L}{g_c} \left[R_b \ddot{R}_b + \frac{3}{2} \dot{R}_b^2\right] \tag{3-9}$$

Equations (3-8) and (3-9) can be combined to give

$$(P - P_\infty) = \frac{R_b}{r}\left[(P_b - P_\infty) + \frac{\rho_L}{2g_c} \dot{R}_b^2\right] - \frac{\rho_L}{2g_c} \left(\frac{R_b}{r}\right)^4 \dot{R}_b^2 \tag{3-10}$$

which is identical to Equation (33) of NEDE-20942-P. (It is noted that several misprints occur on page 20 of NEDE-20942-P. P_∞ in the right hand sides of two equations following Equation (33) should be replaced by P_b and the second term in the left hand side of Equation (33) should be

replaced by $\frac{\rho_L}{2g_c}\left(\frac{R_b}{r}\right)^4 \dot{R}_b^2$).

One certain conclusion that can be drawn from Equation (3-10) is that the pressure at any point in the infinite pool surrounding a bubble generally will not vary with time in the exact same manner as the bubble pressure. It is rather surprising to see the following statement appear on page 21 of NEDE-20942-P, i.e., "It is reasonable to assume that the pressure at any point in the pool will vary with time in the same manner as the bubble pressure. Since the bubble pressure time-history is known (from bubble dynamics model), Equation (34) can be used to construct pressure-time curves similar to Figure 6 for any point in the infinite pool." The only similarity between the pressure-history of any point in the infinite pool and that of the bubble is that when the pressure at any point in the infinite pool reaches maximum (minimum), the bubble pressure will reach maximum (minimum) too. It is indeed very difficult to see how Equation (34) of NEDE-20942-P can be used to construct pressure-time curves similar to Figure 6 of the same report for any point in an infinite pool. It is suggested that the vendor clarify and answer the objections raised here.

In addition to some misprints pointed out earlier, it is noted that Equation (28) of NEDE-20942-P is the result of conservation of mass, instead of conservation of momentum as stated in the same report. Also noted is that the solution given in Equation (30) of the same report is that of Equation (28) instead of Equation (29) as stated.

3.2 Boundary Effects and Pressure Distribution

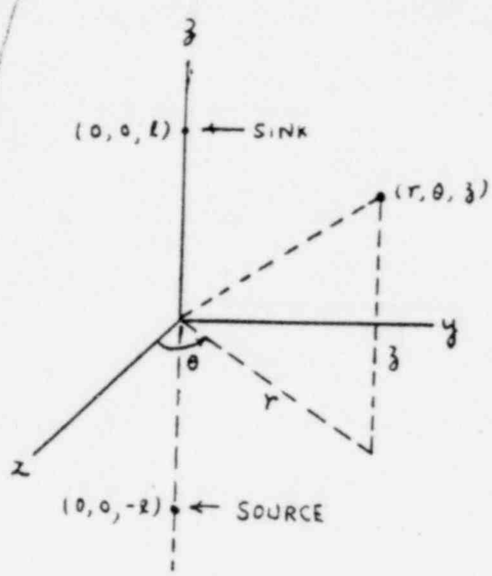
The boundary conditions stated in Section 3.3.2 of NEDE-20942-P are all adequate. It should be pointed out, however, that the mathematical

treatment related to boundary conditions as given in Section 3.3.3 of the same report is rather defective. It fails to mention clearly the particular condition on which the image method can be applied to satisfy the pool free surface boundary condition. It simply states that the maximum and minimum pressures occur when $\dot{R}_b = 0$ without giving any reason (the reason can be given only after the time-dependent solution is given, which, surprisingly, has never been mentioned).

To satisfy the free surface boundary condition, on page 21 of NEDE-20942-P, it is stated that "...it sufficies to balance each bubble (real and imaginary) by a "sink" which is the mirror image of that bubble but its pressure field has the opposite sign". Based on Equation (3-6), it is seen that, unlike the velocity field, a new physically acceptable pressure field is not generated by simply changing the sign of a known physically acceptable pressure field (which, by definition, is a pressure field compatible with basic equations of motion). Thus it seems that the previously quoted statement needs some further explanation. A sink, strictly speaking, should be defined as the mirror image of the source but its corresponding velocity field has the opposite sign. A sink can be used to satisfy the free surface boundary condition approximately (a free surface boundary condition is well approximated if the gradient of pressure along any direction in the free surface is much smaller than that along the direction normal to the free surface) if the following condition is satisfied, i.e.,

$$\left|\dot{Q}\right| >> \frac{3Q^2 \ell r}{2\pi \left(r^2 + \ell^2\right)^{5/2}} \tag{3-11}$$

for any point on the free surface. (It is noted that the true meaning of Equation (3-11) is explained in Figure 1). Equation (3-11), apparently, can be satisfied if the distance between source and sink is large enough.



P = pressue due to sink and source

$$\left.\frac{\partial P}{\partial r}\right)_{z=0} = \frac{3Q^2 \ell^2 \rho_L r}{4\pi^2 (r^2+\ell^2)^4}$$

$$\left.\frac{\partial P}{\partial z}\right)_{z=0} = -\frac{\rho_L \ell \dot{Q}}{2\pi (r^2+\ell^2)^{3/2}}$$

EQ. (3-11) is equivalent to:

$$\left| \left.\frac{\partial P}{\partial z}\right)_{z=0} \right| \gg \left| \left.\frac{\partial P}{\partial r}\right)_{z=0} \right|$$

(r, θ and z are cylindrical coordinates, $z = 0$ is the free surface)

Figure 1. Pressure Field Due to Sink and Source

If this condition is satisfied, then the second term in the right hand side of Equation (3-6) can be dropped. Thus we conclude that the approximate pressure field of a sink is the negative of that of a corresponding source.

Based on the previous discussion, it is easy to see that the pressure field inside the pool can be approximated as

$$P - P_\infty = R_b \left[(P_b - P_\infty) + \frac{\rho_L}{2g_c} \dot{R}_b^{\,2} \right] \sum_{i=1}^{\infty} \frac{K}{r_i} \qquad (3\text{-}12)$$

where K and r_i are defined in page 22 of NEDE-20942-P. Unlike Equation (35) of NEDE-20942-P, this equation is time-dependent and can be used to calculate the pressure at any point in the suppression pool at any time if the history of R_b is known (it is noted that P_b is given by Equation (3-9).)

If we consider only the period after the bubble is formed, i.e., when $\dot{m}_b = 0$, then Equation (25) of NEDE-20942-P leads to

$$P_b = \alpha R_b^{-3K} \tag{3-13}$$

immediately. Here α is some constant. Equation (3-12) coupled with Equation (3-13) implies that

$$\frac{d(P - P_\infty)}{dt} = - \dot{R}_b \left[2P_\infty + (3K - 2)P_b + \frac{\rho_L}{g_c} \dot{R}_b^2 \right] \sum_{i=1}^{\infty} \frac{K}{r_i} \tag{3-14}$$

Since $\left[2P_\infty + (3K-2)\, P_b + \frac{\rho_L}{g_c} \dot{R}_b^2 \right] > 0$ (an immediate result of the fact that $K > 1$) and $\sum_{i=1}^{\infty} \frac{K}{r_i} > 0$ for any point in the pool (which includes wall and floor, but not free surface), an immediate conclusion of Equation (3-14) is that P reaches an extremum if and only if $\dot{R}_b = 0$. A further calculation shows that when $\dot{R}_b = 0$

$$\frac{d^2(P - P_\infty)}{dt^2} = - \ddot{R}_b \left[2\, P_\infty + (3K-2)P_b \right] \sum_{i=1}^{\infty} \frac{K}{r_i} \tag{3-15}$$

The implication of Equation (3-15) is obvious, i.e., when $\dot{R}_b = 0$

$$\ddot{P} > 0 \text{ if } \ddot{R}_b < 0, \text{ and } \ddot{P} < 0 \text{ if } \ddot{R}_b > 0. \tag{3-16}$$

Thus we conclude that P reaches maximum (minimum) if and only if P_b reaches minimum (maximum). With Equation (3-13) in mind, we reach the following conclusion, i.e., if $\dot{R}_b = 0$, then

$$\begin{aligned} R_b &= R_{tmax} \\ P &= P_{min} \\ P_b &= P_{bmin} \end{aligned} \tag{3-17}$$

or

$$R_b = R_{bmin}$$

$$P = P_{max}$$

$$P_b = P_{bmax}$$

Equation (3-17) is given on page 24 of NEDE-20942-P without giving any explanation. Since the derivation (as given here) of Equation (3-17) is as complicated as any derivation given in NEDE-20942-P, it is recommended that either the validity of this derivation be confirmed or another proof given.

Equation (36) and (37) of NEDE-20942-P are the immediate results of Equation (3-12) and (3-17). P_{max} and P_{min} certainly can be solved numerically through the use of these two equations.

Again, it is questioned why the knowledge of local values of P_{max} and P_{min} is sufficient for plotting local pressure vs. time as stated on page 22 of NEDE-20942-P. Time dependence of $P - P_\infty$, as given in Equation (3-12), is not identical to that of $P_b - P_\infty$ and it appears that there is no justification for assuming it.

There is no other criticism on the analytical model of pool response as given in NEDE-20942-P.

4. TRANSLATIONAL MOTION OF THE BUBBLE

Section 3.4 of NEDE-20942-P gives a very confusing presentation of the analytical model of translational motion of the bubble. No assumptions are listed and discussed. Several terms used are not defined. Additional information is needed before a complete evaluation of this model can be pursued.

Although it is impossible to pursue a complete evaluation of this model, a serious mistake about this model can be pointed out. It is stated on page 25 in NEDE-20942-P that the force of buoyancy results in a one g acceleration upward. This statement is not only misleading but, in fact, a mistake. According to the result given on page 467 of Reference 3, a massless spherical bubble immersed in an infinite incompressible irrotational fluid will rise with a 2g acceleration, instead of a one g acceleration. In Amendment No. 1 of NEDE-20942-P(Reference 2), in response to a question raised, an attempt is made to justify the one g acceleration. This attempt; however, is a total failure because so called apparent mass (in most books, it is called virtual mass) is treated as both inertial mass and gravitional mass. As a matter of fact, the concept of apparent mass is devised to account for the resistance of fluid. Thus apparent mass can only be considered as inertial mass but never be considered as gravitational mass. The use of apparent mass as demonstrated in Amendment No. 1 of NEDE-20942-P, is apparently a mistake.

As indicated in previous discussions, the pool response model presented in NEDE-20942-P will be useless in the period just before the bubble breaks through the free surface. A further discussion of dynamic loads in this period is desirable.

5. SUPERPOSITION OF PRESSURE WAVES

Section 3.5 of NEDE-20942-P was substantially revised in Amendment No. 1 [2] of NEDE-20942-P. The evaluation of the analytical model of superposition of pressure waves, therefore, will be carried out after making a careful study of this amendment.

III. RECOMMENDATIONS AND CONCLUSIONS

As repeatedly demonstrated in previous discussions, a major portion of NEDE-20942-P is not written adequately. As a matter of fact, part of this report is so confusing that a meaningful evaluation of it is difficult to make.

Specifically, it is recommended that;

(1) The areas of concern expressed in the main body of this critique and briefly summarized below be fully addressed and misprints as pointed out previously be confirmed.

(2) Scales be attached to all figures and diagrams; other specifications, e.g., positions and times of data taking and so on, be supplied so that the diagrams and figures will be useful in terms of assumption evaluation.

(3) The implicit assumptions found in the process of review and briefly summarized below be confirmed, and the claims of conservatism be fully supported by a definite argument.

The areas of concern and implicit assumptions found are summarized below:

Areas of concern:

(a) In the pipe clearing transient model, the mass flow rate-time relation in the period of valve actuation is assumed to be linear. If a slight deviation from this assumption causes a substantial change of the theoretical prediction of the distribution time-history of fluid properties inside the pipe, then the validity of this assumption is in doubt.

(b) An important assumption dealing with the dynamic behavior of an oscillating bubble and pool response is that the size of the bubble must be small compared with the distance between the center of the bubble and any

point on the boundary of the pool or the surface of another bubble. It is suggested that the validity of this assumption be carefully evaluated.

(c) The initial conditions for bubble oscillation as listed in Sec. 3.2.3 of NEDE-20942-P are considered extremely unrealistic in view of the fact that the position of bubble formation is now assumed to be four feet away from the exit of the ram's head. It is obvious that these initial conditions and the position of bubble formation are interdependent. If the position of bubble formation is considered as a parameter in the bubble dynamics model and is adjusted to remove the apparent discrepancy between the data and the predicted values (as has been done by the vendor), then the initial conditions for bubble dynamics must also be considered as interrelated parameters and be adjusted as the position of bubble formation is adjusted.

Another concern related to the initial conditions for bubble dynamics is the assumption that both the exit of the pipe and the ram's head are in a choked condition. This leads to the conclusion that there must be shock in the region between the pipe exit and the ram's head. The effect of this shock has not been addressed. If shock does not occur, the choking condition might not be correct.

(d) The "efficiency" of the bubble formation process η is another paramenter of the bubble dynamics model. In order to bring the experimental data closer to predicted values, η is determined to be less than 0.1. This means that more than 90% of the energy stored in the air will be lost before the bubble formation is complete. Unless this factor can be calculated by another independent formula, the determination of η from a small body of data is not convincing and might have the effect of concealing the weaknesses of other assumptions.

(e) It is assumed in the bubble dynamics model that the pool boundary does not affect the motion of the bubble. Our discussion indicates that this assumption is non-conservative in its effect on predicting the pressure load on the pool walls. However, in a case where the bubble radius is much smaller than the distance between the center of the bubble and any point on the boundary, the non-conservatism is judged insignificant.

(f) The time-dependent solution of the pressure field which satisfies the boundary conditions has not been given in NEDE-20942-P. It is only assumed that the pressure at any point in the pool will vary with time in the same manner as the bubble pressure. It further states that knowing local maximum and minimum pressures is sufficient for plotting local pressures vs. time. Contrary to these assumptions, a time-dependent solution [Equation (3-12)] derived in the process of our review indicates otherwise. Unless Equation (3-12) is wrong, these two particular assumptions are incorrect.

(g) As explained in our discussion on the translational motion of the bubble, the rising acceleration of the bubble due to buoyancy and drag is 2g, rather than one g as stated in Sec. 3.4 of NEDE-20942-P. One of the results of a larger bubble rising acceleration is the earlier collapse of a basic assumption of the bubble dynamics model, i.e., the effect of variation of pressure with elevation is negligible.

(h) It is also mentioned in Sec. 3.4 of NEDE-20942-P that the preferential direction of expansion and contraction will contribute to the vertical motion of the bubble in water. A substantiation to this statement is needed before an evaluation of it ca. be made.

(i) The dynamic models for the oscillating bubble and pool response, as discussed in NEDE-20942-P, will be totally useless in the period just before the bubble breaks through the free surface.

Implicit assumptions found:

(j) The change of total bubble kinetic energy is considered negligible.

(k) Fluid properties P_b, ρ_b and e_b of the bubble are position independent.

(l) The condition as given in Equation (3-11) of this report is valid.

This report is concluded with the following judgement on the reliability of safety-relief valve discharge analytical models as presented by NEDE-20942-P.

(1) The pipe clearing transient model is considered acceptable if concerns expressed in (a) and (c) are fully addressed.

(2) The bubble dynamics model is considered very unreliable. The concerns expressed in (b) and (e) are considered minor if the bubble radius is not comparable to the distance between its center and any point on the pool boundaries. However, the concerns expressed in (c) and (d) are serious. Unless model parameters discussed in (c) and (d) are determined and confirmed by a large body of test data, this model can not be considered reliable.

(3) The pool response model is judged acceptable if Equation (3-11) of this report is valid and the concern expressed in (f) is addressed.

(4) The analytical model for translational motion of the bubble, as explained in (g), (h) and (i) is judged unacceptable unless a major revision of this model is made.

(5) The model for the superposition of pressure waves will be evaluated in another report.

(6) Based on the judgement of the individual models and the fact that the individual models are interrelated and that little substantiation of the claims of conservatism is given in NEDE-20942-P, the safety-relief valve discharge analytical models as a whole as presented in the same report are judged unreliable at this stage in time.

IV. REFERENCES

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2. P. Valandani, Safety-Relief Valve Discharge Analytical Models (Amendment No. 1), General Electric Class III Report, NEDE-20942-P, January 1976.

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