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either as zero or unity depending on the point of interests. For example, an efficiency of zero is recommended for the analysis of environmental impact due to the liquid effluent released from light-water reactors.[1] The assumption of zero efficiency gives the most conservative evaluation of environmental impact, while it is the least conservative assumption for the shielding evaluation of the filter. In this paper, a mathematical model is developed to calculate a realistic filter efficiency. Throughout the presentation, efficiency is defined as a fraction number of filtered suspended solids with respect to that in the feedwater.

As a result of crud barrier formation, the average size of particles that can pass through a filter decreases as filter time increases. Here, filter time is defined as a time period during which the filter is in service. Efficiency can be expressed as

$$E(t) = \frac{\int_{p(t)}^{R} f(r)\, dr}{\int_0^R f(r)\, dr} \quad , \tag{1}$$

where

$E(t)$ = time-dependent filter efficiency

$f(r)$ = particle size distribution function

r = particle size, diameter in μm

$p(t)$ = average pore size of a filter in μm

R = maximum r in μm.

A typical particle size distribution can be approximated as[2]

$$f(r) = A \exp(-Br) \sin\left(\frac{\pi r}{R}\right) \quad , \tag{2}$$

where A and B are adjustable constants to fit the experimental data into Eq. (2). Since

$$\frac{df(r)}{dr} = 0 \text{ at } r = M \,[M \text{ is } r \text{ at maximum } f(r)] \quad ,$$

$$B = \frac{\pi}{R} \cot\left(\frac{\pi M}{R}\right) \quad , \tag{3}$$

then

$$E(t) = \frac{\exp(-BR) + \exp(-BP) \cdot \left[\frac{BR}{\pi} \sin\left(\frac{\pi P}{R}\right) + \cos\left(\frac{\pi P}{R}\right)\right]}{1 + \exp(-BR)} \quad . \tag{4}$$

Equation (4) is time dependent, since P(t) is expected to be time dependent.

An average filter efficiency, $\overline{E}$, can be obtained by integrating Eq. (4) over filter lifetime, T. Hence,

$$\overline{E} = \frac{1}{T} \int_0^T E(t)\, dt \quad . \tag{5}$$

To solve Eq. (5), it is necessary to know P(t) as a function of filter time. The simplest case would be "no crud barrier formation." In this case, P(t) becomes time independent and equal to the absolute rating, ξ. Therefore, the average filter efficiency for this case is

$$\overline{E} = \frac{\exp(-BR) + \exp(-B\xi) \cdot \left[\frac{BR}{\xi} \sin\left(\frac{\pi \xi}{R}\right) + \cos\left(\frac{\pi \xi}{R}\right)\right]}{1 + \exp(-BR)} \quad . \tag{6}$$

If the crud barrier is formed in such a way that P(t) decreases linearly as filter time increases, then

$$P(t) = \xi \left(1 - \frac{t}{T}\right) \quad . \tag{7}$$

The average efficiency for this case then becomes

$$\overline{E} = \frac{1}{1 + \exp(-BR)} \left\{\exp(-BR) + \frac{R}{\xi(B^2R^2 + \pi^2)} \times \left[2BR - \exp(-B\xi) \cdot \left(\frac{B^2R^2}{\pi} - \pi\right) \sin\left(\frac{\pi\xi}{R}\right) + \exp(-B\xi) \cdot (BR - \pi) \cos\left(\frac{\pi\xi}{R}\right)\right]\right\} \quad . \tag{8}$$

The two examples presented above for the average pore size, P(t), are chosen only to demonstrate the calculational procedure and do not necessarily represent the actual situation. The actual situations may involve more complicated time dependence of P(t). Numerical integrations of Eq. (5) using digital computers can be used for these cases.

The mathematical model presented here is based on theoretical consideration of a simplified situation where particle size distribution and average pore size can be approximated analytically. Throughout this analysis, such factors as shape and hardness of particles are not incorporated into the formalism explicitly but, rather, in a "statistically averaged" fashion. However, this simplified formalism is consistent with realistic analysis, since the particle size distribution and average pore size are determined by a statistically averaged fashion in most cases.[3] As discussed at the beginning, efficiency is defined as the fractional number of filtered particles with respect to that in the total feedwater. However, this analytical model can be utilized for weight-based efficiency or radioactivity-based efficiency with a slight modification correlating specific weight or specific radioactivity with particle size. The comparison study of this analytical model with experimental data is under way, but the data[3] obtained at OCONEE indicate that "crud barrier formation" plays an important role in the overall filter efficiency. According to particle size distribution, 4-μm absolute filter can filter only 33%, while actual experimental data of ^{54}Mn, ^{58}Co, and ^{60}Co indicate an overall efficiency of 87% for the 4-μm filter.

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1. Draft Regulatory Guide 1.BB and 1.CC, "Calculation of Releases of Radioactive Materials in Liquid and Gaseous Effluents from Water Reactors," U.S. NRC (1975).

2. T. VAN DEN VERG and T. W. LANCEY, "Backwashing a Stacked Disk Filter," *Trans. Am. Nucl. Soc.*, **17**, 322 (1973).

3. D. L. UHL, Ed., "Oconee Radiochemistry Survey Program (Semiannual Report)," Lynchburg Research Center (1975).

6. The Thermal-Hydraulic Code, SOPHT, as a Design Tool, *Wm. J. Garland (Ontario Hydro)*

An accompanying paper[1] describes the development of a code for the simulation of primary heat transport (SOPHT) systems and its use as an operational tool. This paper describes its use as a design tool.

The code accepts, as input, the thermal-hydraulic circuit specification; system volumes are modeled as "modules" in which mass and energy balances occur while system pressure drops and flows occur in "links" connecting the modules. Superimposed upon the plant heat and mass transport system is the control system. Although the control system is hard programmed, it is modular in design and, hence, lends itself to easy modification. The code has its boundary conditions supplied solely via input data. These conditions are both flexible

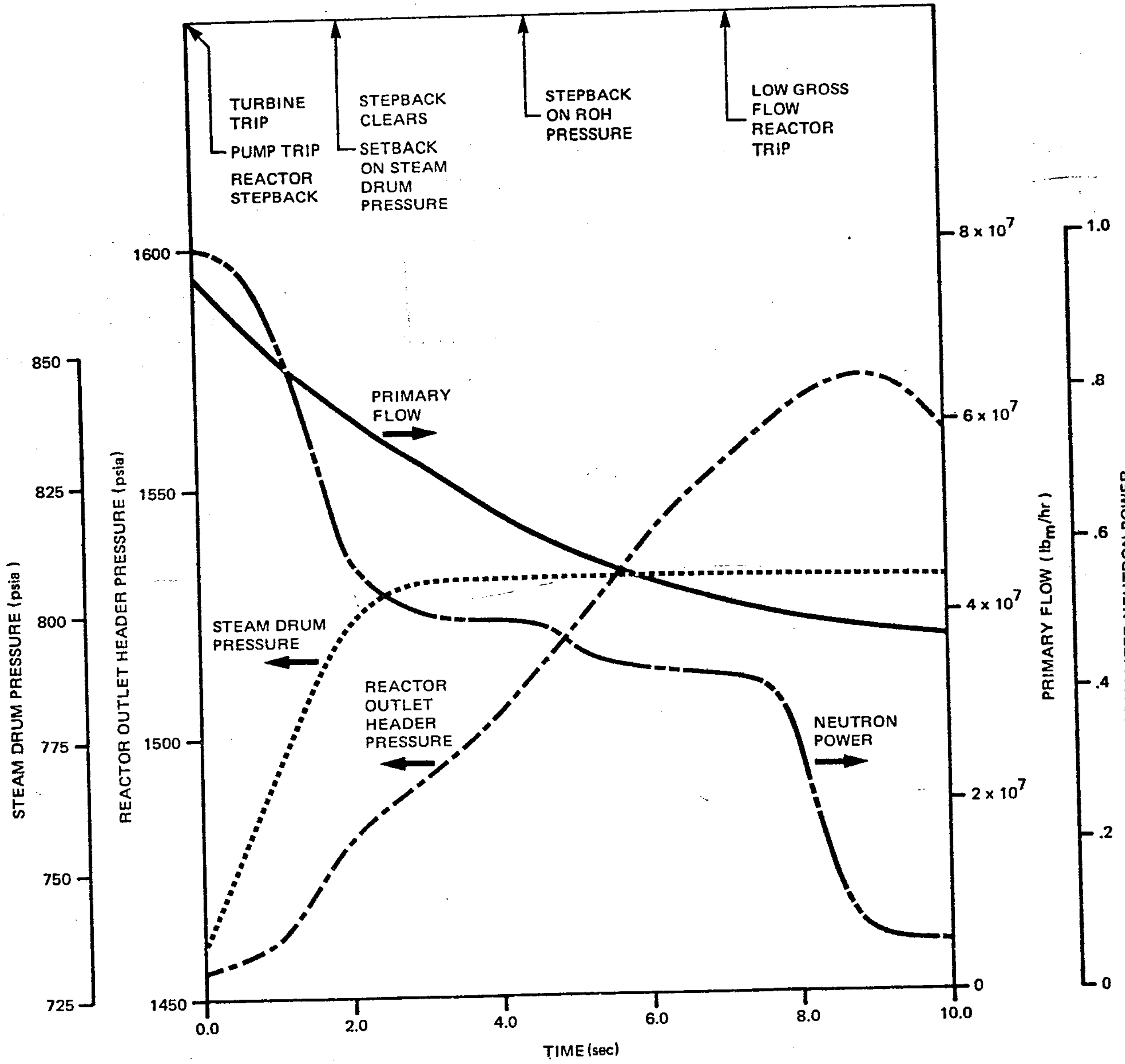

Fig. 1. Steam drum pressure and primary system pressure, flow, and power, as a function of time for a total loss of CLASS IV power.

and exhaustive and allow the user to, say, hold the pressure, enthalpy, or flow at one point in the circuit, or put a variable resistance in a flow link, etc.

This flexibility in plant specification plus the capability to generate steady-state and transient solutions yields a code suitable for use in design. Possible applications include equipment studies and sizing for such items as main pumps, valves, pressurizer interconnect lines, and boiler swell. Maneuvering rate studies, definition of operating transients for stress analysis, and the study of controller action are also possible.

To illustrate the above uses, consider the case of a total loss of normal, interruptable power, denoted as a "CLASS IV power failure," for a typical CANDU-PHWR. This represents an operational transient needed for the stress analysis of the steam generators. The figure shows, as a function of time, two of the system parameters affecting the stress analysis. The loss of CLASS IV power occurs at time t = 0.0. This immediately initiates a trip signal to the turbine governor valves and causes a loss of power to the main heat transport pumps, feedwater pumps, reheater drain pumps, and turbine condenser cooling water pumps. These conditions are imposed on the simulation using input data changes only. The subsequent sequence of events is shown in Fig. 1. The loss of the turbine causes a fast, controlled power reduction stepback to 60% full power. This signal clears at t = 2.0 sec, but a high drum pressure causes a further slow reduction in power via a setback signal. High primary system pressure gives a second stepback and low primary flow finally trips the reactor. This takes the plant through the initial high-pressure transient. The use of the resulting transient in the stress analysis may lead to the conclusion that the transients are unacceptable. In that event, the action taken may be to resize the pressurizer interconnect lines. This is easily done, again via input data.

Thus, the practicality of using SOPHT as a design tool has been demonstrated. It is presently being used in the design of the Darlington Generating Station, Pickering "B" Generating Station, and will undoubtedly see use in other planned stations.

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7. Seismic Qualification of Main Steam Safety Valves, *Y. S. Lai (Dresser Ind)*

Main steam safety valves (Fig. 1)[1] for PWRs are complex pieces of mechanical equipment. The major components stacked between the compression screw and nozzle are held to the positions by the compressive spring force only. The boundary conditions of the major components are extremely difficult to determine for a theoretical dynamic analysis to demonstrate the safety-valve seismic operability.[2]

To study the dynamic behavior of the main steam safety valve under seismic disturbances, two full-size Dresser CONSOLIDATED 3777Q safety valves[1] were tested on a shaker table. The conclusions are presented below:

1. Under either a vertical or horizontal vibration, the safety valves with discharge elbow attached behave as an axisymmetric structure.

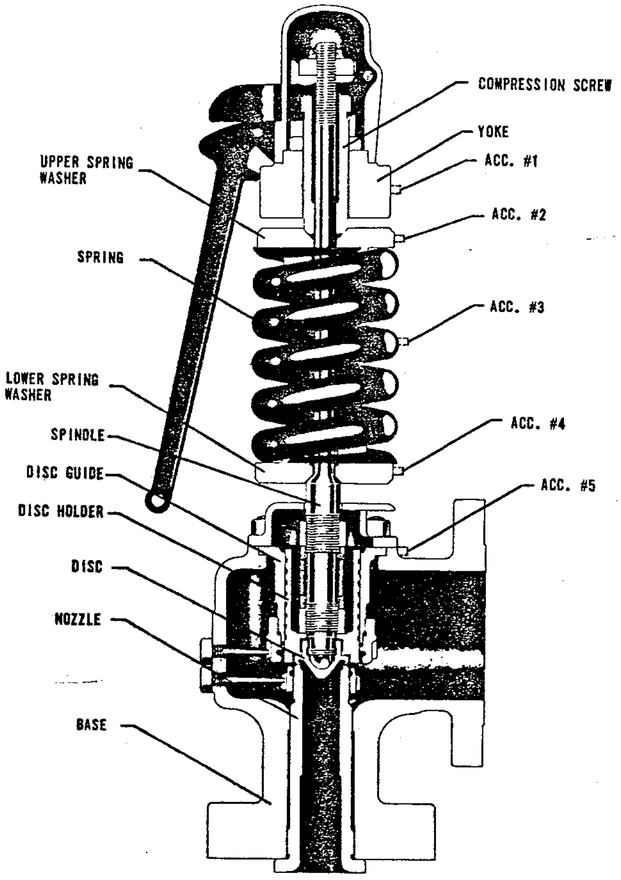

Fig. 1. Dresser main steam safety valve (yoke support is not shown).

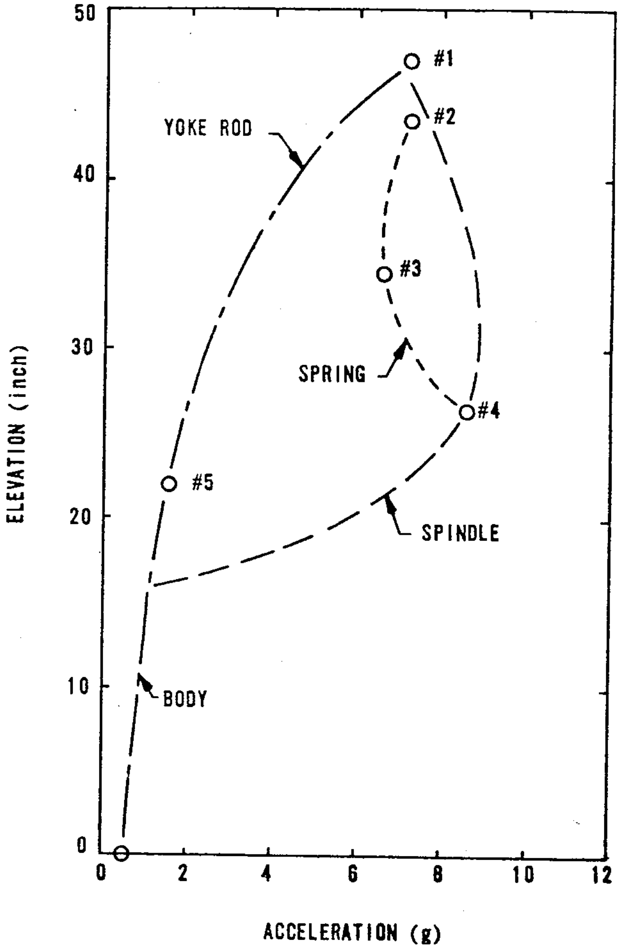

Fig. 2. Components peak accelerations (under 0.5-g and 16-Hz horizontal base excitation).

2. Vertical excitation has no effect on the safety valve opening and closing strokes.

3. The safety valves vibrate as a multi-degree-of-freedom system under a horizontal disturbance. Typical component accelerations measured by the accelerometers shown in Fig. 1 were plotted in Fig. 2. Large spindle deflection and components rigid body motion is critical to the safety-valve functional operability.

4. The loose components stacked between the compression screw and nozzle play the most important role in the safety-valve dynamics. The single-degree-of-freedom model being used by industries today was found grossly inadequate. Due to complex motion of the loose components, an adequate mass matrix and stiffness matrix cannot be formulated by presently available techniques for a detailed theoretical analysis. Seismic operability qualification by analysis is, hence, beyond the state-of-the-art of engineering science. Being unable to theoretically predict the safety-valve dynamic responses, an equivalent static test cannot be conducted to establish the seismic operability. Therefore, the main steam safety-valve seismic functional operability qualification can only be accomplished by appropriate dynamic tests.

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1. *Valves for Nuclear Service*, Dresser Industrial Valve & Instrument Division (1974).
2. U.S. AEC Regulatory Guide 1.48 (1973).