LIAISON TO FOREIGN CONTAINMENT RESEARCH

CONTAINMENT POOL DYNAMICS

A Discussion of Activities, Goals, and Issues

Edward W. McCauley

Lawrence Livermore National Laboratory
University of California
Livermore, California

January 29, 1981

F305

PREFACE

Under contract to the U.S. NRC (FIN #A-0116)[a], and as administered by Dr. T. M. Lee, the Lawrence Livermore National Laboratory (LLNL) is conducting research whose goal is quantified understanding of containment pool dynamics (a) as occurs in the G.E. Mk II BWR containment design under hypothetical loss-of-coolant accident (LOCA) conditions and (b) as occurs in the G.E. Mk III BWR containment design under safety relief valve operation. The results of these researches are directed to support of advanced containment code development and to provision of both theoretical understanding and confirmatory data to meet the interests of the related NRC licensing activities.

Knowledge of containment response under SRV loading conditions is primarily supported by observation of actual measurements obtained in operating plants. As such, satisfactory understanding of the loads, in a regulatory sense, is only limited by the timeliness with which such in-plant test programs are conducted and the completeness of the related measurements system. Containment response under LOCA conditions is quite different since no in-plant utility sponsored test programs are available or planned. Also, no related full or large scale research is sponsored by the U.S. NRC. Rather, heavy emphasis is placed on utility sponsored work, which, for reasons of economy, is based on the full scale unit cell concept to represent vent pipe/wetwell performance. This also includes extensive work on small scale multivent arrays to extrapolate the unit cell results to plant performance. The unit cell concept has met with reasonable success in treatment of

---

[a] U.S. NRC, Division of Water Reactor Safety Research, Analysis Development Branch (Dr. S. Fabic, Chief)

understanding of the physical processes and identification of the facility dependent effects effective goals can be set for useful calculational tools; these may prove to be empirical.

Mk II Containment (LOCA)

Due to recognition by the U.S. NRC and associated foreign agencies in West Germany and Japan of difficulties in length scaling of two-phase flow phenomena, particularly as associated with the LOCA chugging stage, plans were formulated in 1976 - 77 to develop full scale multivent confirmatory research programs to address the Mk II containment design in general and LOCA loads in particular. As a result, testing began in two experimental programs of interest to the U.S. NRC in the spring, 1979:

> Full Scale Multivent Mk II Containment Response Test Program (JAERI-CRT), Japan and
>
> Full Scale Multivent Pressure Suppression System Test Program (GKSS-PSS), West Germany.

These programs are now each near their mid-point; they are both expected to reach completion in late FY82.

The U.S. NRC/LLNL Liaison to these programs was established in late FY79 with the primary purpose to meet the above goals of understanding and data.

The LLNL Liaison initiation at the GKSS Laboratory in June of 1979 was actually a re-establishment of participation in the PSS work begun with the PSS research planning meetings at the GRS in Koln, FRG and at GKSS in December, 1976, attended by NRC staff and this writer. As a consequence, the collegial relationship with the GKSS staff, necessary to an effective Liaison, was rapidly gained by LLNL. As a result of regular working visits at GKSS the Liaison has developed NRC access to all original test data, program documentation, and an opportunity for program participation and consulting.

staff requirements (initiated in November, 1979) for their own separate data evaluations, was met with a strong cooperation by the JAERI staff and the Japan Mk II Owners' Group (JOG). The significant impact of this unplanned CRT program activity, in context with both limited staff and budget, introduced a six month delay in the previously planned CRT work. The Liaison was maintained during this period and suggested program enhancement activities, similar to those at GKSS, were acted upon through the generous cooperation of Mr. M. Shiba, Head of Safety Lab 1, Mr. K. Namatame, CRT Program Leader, and his associate Dr. Y. Kukita. In particular, tests were reinitiated in October, 1980 with an improved orientation of wetwell pressure transducers and the inclusion of 4 flush diaphragm pressure transducers loaned by the JOG. An earlier strong interest was taken by CRT staff in Liaison consultations regarding use of such flush diaphragm pressure transducers in the wetwell and in developing a complete modal characterization of the existing facility wetwell for future use in fluid-structure interaction (FSI) evaluation. Their limited staff and funding, however, precluded such action. Discussions regarding difficulties[a] concerned with future quantified application of data obtained with their nominal 500 Hz high speed data acquisition system has now led to system revision and a nominal 2 kHz data acquisition rate. Recent action by A-8 Task Manager Mr. C. Anderson (NRC-DST), supportive of Liaison concerns regarding needed wetwell pressure measurement system modification and wetwell modal characterization both before and after planned structural modifications has created the opportunity for this Liaison to offer that direct support to the JAERI-CRT program by a combination of transducer loans and supplied services. Resolution of their acceptance of such support is expected shortly.

---

[a] errors in pressure amplitude and frequency, determined through study of the GKSS 8 kHz original data base.

test program (Spring, 1981) will be provided to the U.S. NRC. In preparation for these tests they have been highly cooperative in accommodating special requests by the U.S. NRC to provide enlargement of their measurment system and test matrix. To aid in this data base development, the Liaison has provided extensive consulting in the area of wetwell pressure measurments including unique dynamic characterization of their re-entrant tube type pressure transducers. In addition, several high response flush diaphragm pressure transducers and accelerometers, preserved for reuse from our earlier NRC sponsored Mk I containment research, have been provided as spares for TPC as required during testing.

To date our emphasis is placed on the SRV tests. The startup procedure to be used at Kuosheng plant will, however, follow U.S. NRC regulations and the TPC will make all of this data also available. The resulting SRV response and startup data base will allow this Liaison to provide timely and independent data analyses and evaluations particular to the interests of both research and regulatory staff in the U.S. NRC.

may not be there! LLNL!

Table of Contents

Preface

I. Introduction 1

II. General Phenomena - Mk II Containment

A. Background 2

B. LOCA Phenomena 3

C. LOCA Load functions 6

III. LOCA Representation by the Full Scale Experiments

A. Test Matrices 8

B. Scaling Effects 10

C. Condensation Effects 13

D. Measurement and Data Acquisition Effects 17

E. Issues 18

ISSUES

BWR LOCA - Mk II Containment Design

I. Introduction

The loss-of-coolant accident (LOCA) is a hypothetical event used to define a design basis accident (DBA) in the Boiling Water Reactor (BWR) type central station power plant. As such it provides a maximum credible assault on the integrity of the included containment system. The demonstration of the ability of a proposed containment design to withstand the consequent ~~environment~~ of the LOCA is therefore a subject of major attention in the licensing of these plants.

Due to the massive energy release of the hypothetical LOCA, i.e., initiation by an instantaneous, double ended, offset circumferential rupture of a recirculation line while at full power, no in-plant simulations are practicable and plant-unique LOCA response tests are not conducted. In order to provide a design basis for the so-called pressure suppression system (PSS), which is provided in each plant to defeat the major consequence of LOCA, a severe containment boundary overpressure, the designer uses analytical loading predictions as well as scaled non-nuclear test results. These tests are always scaled in space (volume) and often scaled in length. They have demonstrated that the resulting loading functions are difficult to define since the phenomena which produce them are complex and influenced by the facility in which they are measured.

In order to develop an adequate basis for judgement of the U.S. Mk II containment design safety, all hydrodynamic loads must be identified and quantified. Since no in-plant LOCA tests can be done, such load determinations must be taken from scaled tests. As implied above, an overriding issue is thus identified as the relation between such scaled tests and a full scale plant. To a lessor degree, the relation between tests and a

(c) the ability of all associated structural components to remain intact during tne loads produced by the prolonged LOCA transient so that the design function can be accomplished.

No serious issue appears to be involved in items (a) or (b). Definition of suitable dynamic load functions to confirm item (c) is, however, at issue.

The design features of the PSS are based on the obvious need to provide timely condensation of the steam flowing from the recirculation line break. Adequate design of the in-plant PSS, however, can only be judged through careful consideration of the varied and complex loading functions which arise during the delivery of the drywell fluids to the wetwell pool.

B. LOCA Phenomena

A useful way to describe the LOCA transient is to view it from the wetwell pool. It proceeds in three distinct stages.

1. The first stage is the air clearing transient which impulsively clears the water leg from each vent pipe and delivers a strong pressure pulse to the wetwell pool boundary. In addition, the noncondensible air creates a substantial swell of the wetwell pool whose transient effect is felt both by interspersed structures, through drag loads, and by the drywell floor, due to differential wetwell ullage/drywell pressure. This phase terminates within a few seconds.

At issue during this stage is

(a) the peak floor and wall boundary pressures associated with the vent clearing.

(b) the frequency with which this double-peaked impulsive event is delivered.

(c) the extent and velocity of pool swell as driven by the expelled drywell air.

(d) effect of drywell air carryover in steam.

(e) induced vent pipe forces, their direction and frequency.

(f) for similar conditions of LOCA initiation, the reproducibility of the C/O stage.

(g) effect of major parameter changes (pool depth and temperature, vent submergence, initial break size, wetwell airspace volume) on C/O initiation, extent, and strength.

3. The third and final stage of the LOCA appears under conditions of substantially reduced steam flow and near completion of drywell air carryover ($<1\%$ contained in steam). At this point of low mass flux there begins a serious competition for steam energy removal between the pool and the vent system and no longer can the available delivery supply provide the head necessary to smoothly clear the vents as before. Rather, with a period of 2 to 4 seconds, there occurs a temporary cessation of steam flow from the now reflooded vent pipe which is then followed by a short lived delivery of steam to the pool with an attendant rarefaction at the vent pipe exit as the flow once again terminates. The rarefaction results in an impulsive excitation of the wetwell pool/boundary system. Accompanying pressures oscillations are often strong and exhibit the facility dependent wetwell-system frequency; this is significantly higher than the vent pipe acoustic. This complete phenomena is termed chugging, reminiscent of the early days of the sights and sounds which accompanied operation of the steam locomotive.

The issues involved in the chugging stage are:

(a) the relative simultaneity of a chug initiation among the vent pipes.

(b) the degree of uniformity of chug strength among the vent pipes.

subsequent drywell surface condensation rate is substantially reduced by wall preheating due to an earlier small steam leak, the initial $\dot{p}_{dw}$ of the LOCA will be greater and its terminal point increased. Although not necessarily productive of significant drywell overpressure, the effect on the peak pressure in the wetwell pool which accompanies initial clearing of the vent pipe water leg can be substantial.

With the maintenance of normal drywell boundary temperatures, $\dot{p}_{dw}$ can be controlled to desirable levels. This importance of $\dot{p}_{dw}$ does, however, reinforce its fundamental use to define the initiation of LOCA simulation experiments.

Stage 2 - Condensation Oscillation

Initial steam delivery into the wetwell pool is characterized by a relatively high mass flux and air content. In a typical cycle of C/O the steam-air mixture rapidly clears the vent and enters the pool about one vent diameter. The subcooled pool water rapidly condenses this steam and successfully reduces its interface pressure below the static pool head so that a condition of partial vent reflood is again established. This cycle is repeated at the quarter-wave frequency of the vent pipe and thus is influenced by the vent length and local sound speed of the steam-air mixture. Further, the ullage overpressure provides an influence through its implicit control of reflood height and its consequent effect on the steam and air volume delivered to the pool during each cycle of C/O.

Stage 3 - Chugging

As discussed earlier, the chug event follows C/O as a direct consequence of substantially reduced steam flow and air content. Compared to the smooth harmonic nature of C/O it is quite violent. Because of the interplay between

However, the text matrix is arranged, the completion of it is a complex and expensive task. This suggests that a carefully developed basis for results documentation be considered an integral part of the experimental program. Understanding of what results were obtained must come before attempts to apply them to a separate system. As a minimum, first, or quick-look documentation should focus on test characterization:

(a) test initialization conditions and transducer positions.

(b) derived data, such as the steam mass flow rate history and selected PSD plots and times of the LOCA stages observed.

(c) a characteristic data plot set which exposes primary response by means of a carefully selected subset of the available transducers; such a plot set includes both total test time and expanded time regions to clearly define the measured features of the 3 LOCA stages in context with the multivent nature of the test.

These items provide the necessary basis for rapid and easy intercomparison of the tests as they are developed to confirm (or deny) the fact of satisfactory progress in the test matrix.

Second level documentation should focus on collections of data from related tests to ever improve the limited understandings obtained from the quick-look results. Key items in this effort include

(a) documentation of the degree and extent of test reproducibility, i.e., both global and local for all stages.

(b) presentation of the direct or derived sensitivity of defined measurements to the systematic change of major and minor parameter changes, e.g., peak down and up force at vent clearing (stage 1) as well as total impulse delivered during this period as a function of initial drywell pressurization rate. It should be noted that without an accepted degree of test reproducibility such parametric variation results are, at best, of limited use.

increased positive impulse following the initial vent pipe clearing. This effect can be better envisioned by considering the 1/18 volume scaling of the 7 vent JAERI-CRT facility (20^{o} section) as seen in vertical section through vents 3 - 4 and vents 1 - 6 (Fig. 1); such a narrow channel clearly distorts pool swell. Such effects have been observed by the 2D/3D Mk I containment research at LLNL (NUREG/CR-0761, pg. 2-20 ff). The volume scaling of the 3 vent GKSS-PSS wetwell introduces a different problem since the vent pipes are not distributed in "unit-cell" fashion in the cross section and all wall boundaries are plane, i.e., the virtual wetwell extends in all directions. This can, however, be advantageous since it provides vent pipes whose distance to the adjacent wall vary substantially and thus offer the opportunity to improve understanding of the effect of such fixed walls on pool swell. Figure 2 has been developed to display the GKSS wetwell in this light.

There are other effects due to volume scale. Three volumes are of possible influence on the LOCA representation. The first is the drywell. Although its volume may be correct on a per-vent basis, its shape and surface area are not representative of a plant drywell. The effect of these features are most influential during the air clearing transient. However, by conditioning the initial steam delivery rate to achieve the desired p_{dw}, at least a common-basis event initiation can be produced. A high degree of confidence must therefore be placed on the adequacy of the chosen p_{dw} to represent this stage of LOCA in a plant.

The subsequent rate of steam delivery will influence the remainder of the LOCA transient. Capable predictions of its delivery rate history from an in-plant break can be developed. Such predictions should be available and closely correlated to the experimental steam delivery (perhaps by definition of equivalent break area) to ensure that all test results can be related to a simulated plant event and are not just "like" a LOCA because the typical 3 stages are observed.

boundary load distribution in the CRT facility. These features, along with the artifact of two separate vent pipe lengths at GKSS, appear to be particularly important since equal opportunity for study of the two facilities' data is not available.

C. Condensation Effects

1. As discussed earlier, the second LOCA stage produces a harmonic-like pressure response in the wetwell. This loading is, however, felt in all parts of the PSS, and produces vent pipe oscillation. Detailed study of the C/O phase indicates that acoustic oscillations do not occur simultaneously at all vents. Rather, it appears that the acoustic in a particular vent can be quiescent for several periods or can be out of phase with its neighbors while they oscillate at their length-determined characteristic frequency. Due to this random behavior, no single pressure transducer response can be expected to characterize the pressure boundary loading from C/O. Further, wall loading information would appear to be of small aid in resolving a C/O characteristic peak overpressure (POP) since no such radial boundaries exist in a plant. Thus, it seems that, at least for the JAERI-CRT facility, measurements along the circumferential shell boundaries and the wetwell floor provide the only surfaces from which plant-like C/O loading can be expected. The CRT facility is unlike any plant containment since its wetwell floor is partially flexible and its shells highly flexible. The radial side boundaries, an artifact of symmetry requirements, are essentially rigid. The GKSS-PSS facility on the other hand, is of relatively uniform flexibility at all walls and on its wetwell floor.

If we ignore for the time being the issue of interaction between the boundary structure and the pool fluid (FSI), a POP envelope can be developed from pressure measurement on the floor below each vent pipe for any given test. The multiple envelopes (i.e., the ensemble from all vent pipes) can

2. The chugging phase produces loads of significance due to their impulsive nature and pool-system excitation capability. Unlike the clearly unsynchronized C/O phase, the chugging appears to be nearly synchronized at each vent. While this statement is agreed with by most investigators, its resolution in detail is subject to several difficulties. The first is the lack of a uniform agreement on the methodology of determining "time of a chug". At least three definitions are in practice: the time of the rarefaction minimum, the time that the subsequent positive gradient crosses the "mean-pressure" axis, and the time of the first positive peak after the initiating rarafaction. This writer subscribes to the first procedure, for the simple reason it appears to be the only time associated with a facility independent event; the piezoelectric pressure transducers of the GKSS-PSS facility, located as they are in the vent exit region where the rarefaction occurs appear to signal the chug event by this rarefaction minimum. The second method requires substantial curve fitting in order to establish a "mean-pressure." This in turn implies knowledge of period, damping, and phase shift of the multiple oscillatory components of this wave. Such modelling is not expected to be accurate enough to provide anything beyond an estimate of timing. The time of first peak after the rarefaction may well be a sound chug event timing method; demonstration is required, however, that this time is not substantially facility dependent. Whatever method is chosen it is needed now. It is clear that sufficient data from GKSS-PSS will be available to substantiate the degree of synchronization which exists in that multivent facility during chugging for future tests (beyond M1-4) since output from non temperature sensitive piezoelectric transducers will be available both within the vent near vent exit and external to the vent at exit level. To this will be added the corresponding absolute flush diaphragm pressure transducer histories at vent exit level, midpool height, and floor (flush mounted).

either not existent or greatly reduced when observed in a large or full-scale test (e.g., enthalpy flux scaling during the air transient).

Characterization of chugging at a plant equivalent boundary involves pressure amplitude and the associated frequencies associated with the actual chug as well as the frequency of events. Event frequency is influenced by air content in the steam, vent steam flux, local pool temperature, and wetwell ullage overpressure. The sensitivity of event frequency to facility artifacts requires clarification in order to place this on a plant basis. Local chug frequencies seem to be predominated by the vent acoustic and the pool system frequency with the pool system frequency dependent on the pool configuration.

An effective method of frequency characterization from a time history lies in its transformation to the frequency domain through a Fourier transformation and computation of the associated power spectial density (PSD). A plot of the PSD shows the frequency distribution of power in the original signal; the power spectral density being defined as the power per unit frequency interval. For a structural system under assessment for modal content, this analysis technique is of fundamental importance to determination of its vibrational modes. For the subject at hand, understanding the several pressure histories, both at boundaries and in or near vent pipes, it is of great utility. Beyond the obvious ability to readily define the relative power and individual freuqencies in the original signal, the PSD can be filtered to exclude selected frequency bands and then inverted to recover, e.g., a pressure history which is both free of the undesireable frequency(s) and properly reconstructed in amplitude. Such treatment has significant utility in study of boundary or system induced artifacts and this manipulation of the real and imaginary transforms to develop a new time history is entirely valid.

associated foreign PAL frequency of 50 Hz, however, limits visualization and correlation to transducer response to 20 ms intervals. Addition of a fast framing camera will readily lower this interval to 1 ms or less and provides a powerful adjunct to the acquired data base, particularly in its application to modeling needs.

E. Issues

The primary issue is development of a consistent, workable, and agreed upon plan for evaluating the data from the separate foreign experiment programs in order to develop quantified information which is of both immediate and long term use to the U.S. NRC. This requires, in addition to routine and timely acquisition of their normal documentation of test results, access to data details, preferably by means of original data tapes and films.

The importance of agreement with these foreign research organizations to include the above discussed characteristic data set in the quick-look report should be encouraged. As a case in point, GKSS-PSS staff now routinely provide expanded-time, high resolution pressure plots of chugging phases. As fundamental as such test characterizations are, little such data is routinely available from the JAERI-CRT work.

Not Tech. Issue

The relationship between observed transducer response (particularly wetwell pressure) and that which would have occurred in a plant, i.e., fluid structure interaction effects, should be quantified. Whatever they are at the GKSS-PSS facility will continue to be present throughout their testing program. Whatever they are at the JAERI-CRT facility has affected the data from 17 tests, future tests can be expected to provide the extreme of rigid boundary response.

With the extensive boundary measurement changes already implemented at GKSS and planned for at JAERI an important move toward a common-basis pressure to believe later observed effects were indeed due to a parametric change in test conditions (and not just random behavior). In a similar way, if the commonality of process or initiating event exists between the two test faciities, the apparent differences become a substantial advantage to understanding of both mechanism and response.

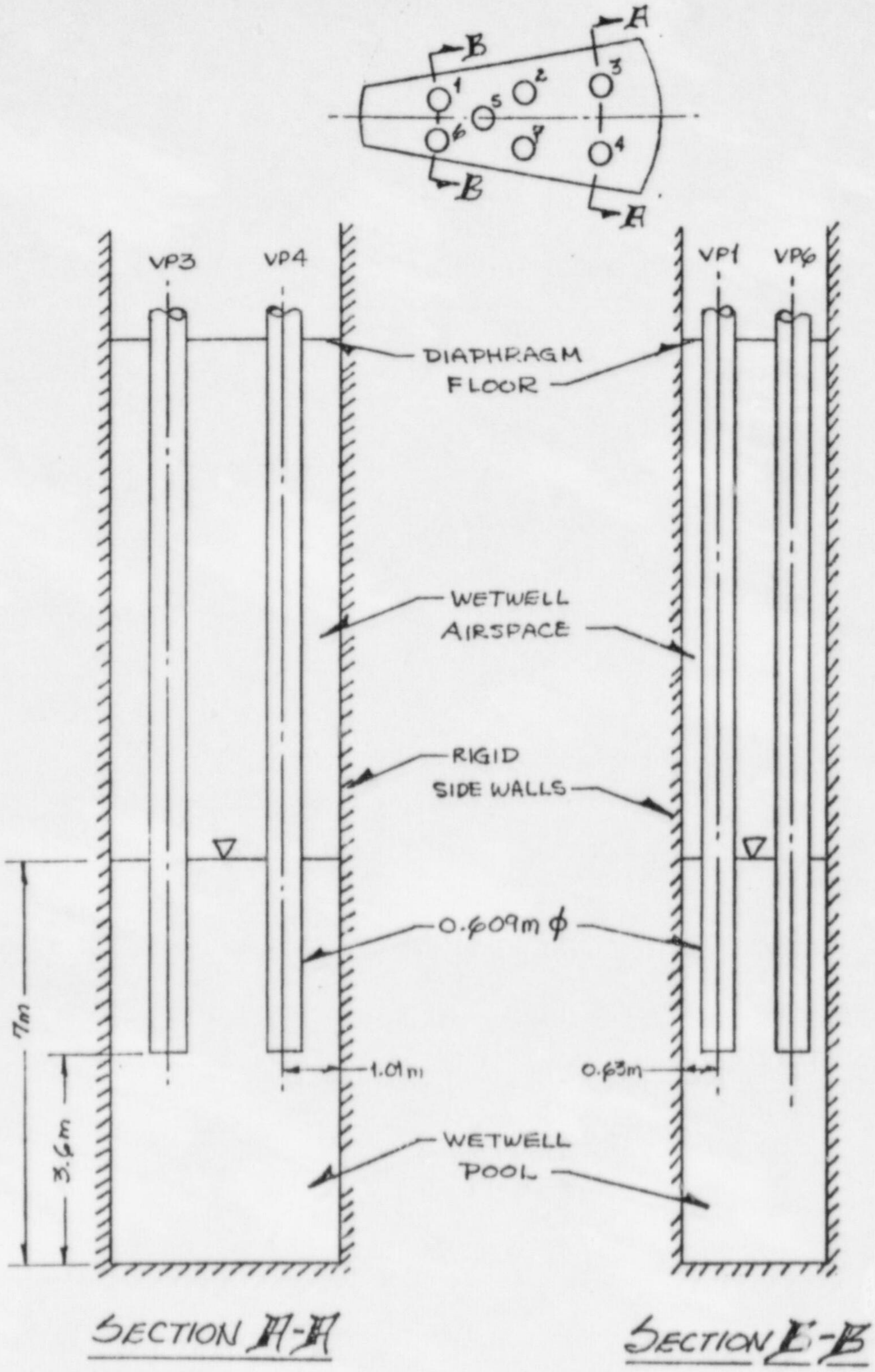

Fig. 1 Visualization of Circumferential Pool Confinement Extremes
JAERI-CRT WETWELL

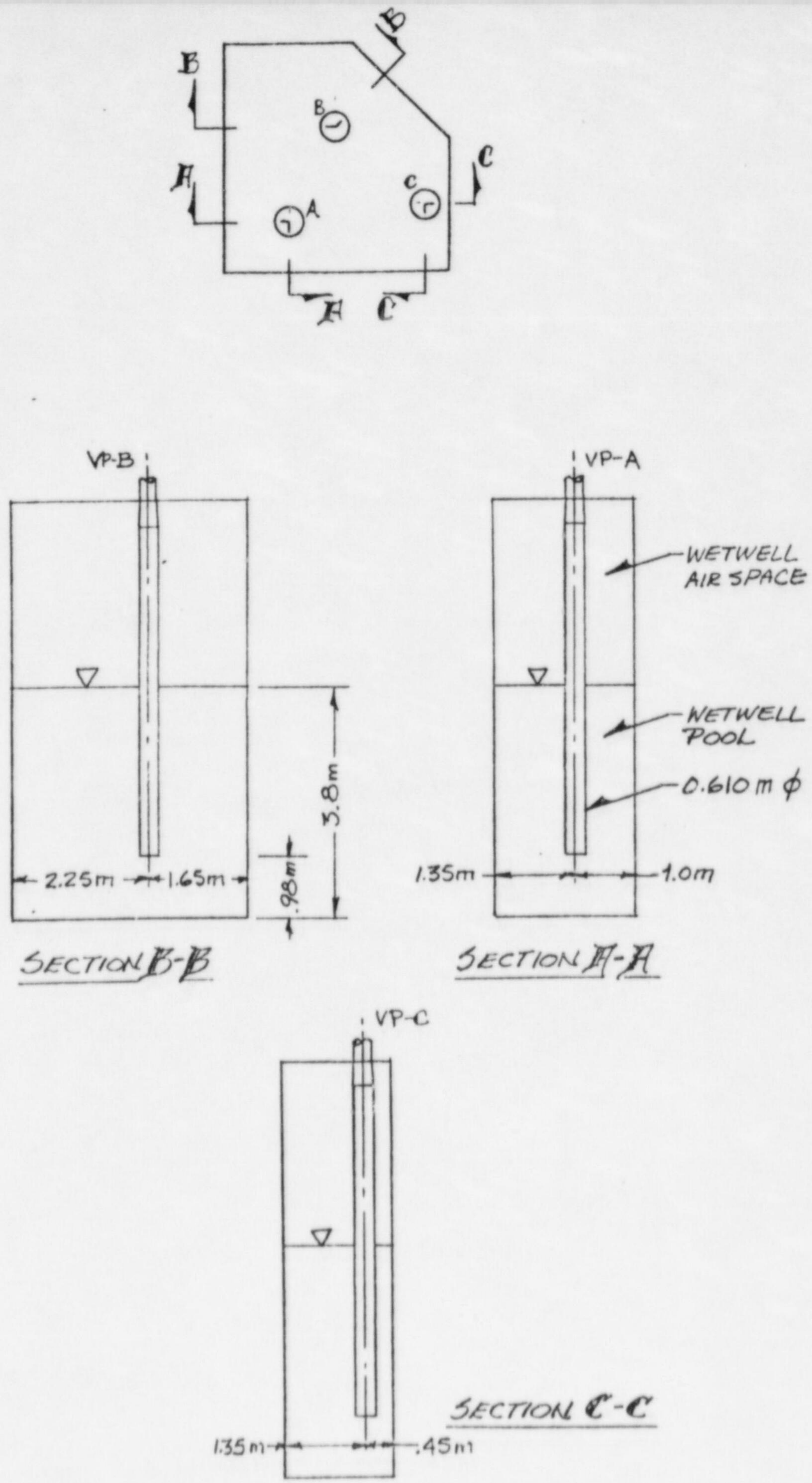

Fig. 2 Visualization of Polygonal Pool Confinement Extremes
GKSS-PSS WETWELL

Lawrence Livermore National Laboratory

NUCLEAR SYSTEMS SAFETY PROGRAM

TF81-110

May 5, 1981

Dr. G. Schultheiss, Director
GKSS-DAS
Forschungszentrum Geesthacht GmbH
Postfach 1160 - Reaktorstrasse 7 - 9
D-2054 Geesthacht - Tesperhude
West Germany

Subject: LLNL Contributed Paper

Reference: International Specialist Meeting on BWR-Pressure Suppression Containment Technology, June 1 - 3, 1981.

Dear Dr. Schultheiss:

Enclosed is an abstract of our paper entitled "A Method for Chug Classification," as you requested. Please note that the title is changed from that given earlier to provide a clearer identification of the information to be presented.

My best regards to you during your preparations for this meeting.

Yours truly,

E. W. McCauley

Edward W. McCauley, P.E., Ph.D.
Thermo Fluid Mechanics Group
Nuclear Test Engineering Division

EWM:lgd

8105.05/2427u

cc: (w/encl)
Dr. T. Lee

F340

A Method for Chug Classification*

E. W. McCauley, H. J. Weaver, and T. J. Altenbach
Lawrence Livermore National Laboratory
Livermore, California, U.S.A.

ABSTRACT

There is much international interest in the response of a boiling water reactor (BWR) pressure suppression system to the late time, steam condensation phase of a postulated loss-of-coolant accident (LOCA). During this late time a process known as chugging occurs in which condensing steam causes large pressure shock waves in the system. There are many factors that seem to affect the size and character of the chugs. However, before these factors can be carefully studied the nature of the chugs must be determined. At the present time, different investigators use widely varying methods of discussing chugs. Often times they even disagree on whether a pressure oscillation is to be considered a chug or not. Pressure oscillations are studied by considering their time histories. Certain events are considered chugs based upon properties that are easily recognizable to scientists and engineers who are familiar with the phenomenon. However, this can be a rather difficult and nebulous task.

In this report a method is presented which provides for general classification of the late time condensation phenomena of chugging as it occurs in pressure suppression tests. The method uses a five (5) character letter code which describes both the spectral (frequency) and temporal characteristics of a chug event. The results are founded on original data obtained from the full scale, multivent, pressure suppression test facility operated by the Institut fuer Anlagentechnik of the GKSS Forschungszentrum Geesthacht GmbH.

---

* This work was supported by the U.S. Nuclear Regulatory Commission under a Memorandum of Understanding with the U.S. Department of Energy.