FORSCHUNGSZENTRUM GEESTHACHT GMBH

T. LEE

GKSS, Postfach 1160, 2054 Geesthacht

Max-Planck-Straße, 2054 Geesthacht
Telefon: (04152) 121
Telex: 0218 712 gkssg
Telegramm: GKSS – Geesthacht

INSTITUT FÜR ANLAGENTECHNIK

Dr. L. S. Tong
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission

Washington, D.C. 20555
U.S.A.

Ihr Zeichen:	Ihre Nachricht vom:	Unser Zeichen:	Bearbeiter:	Telefon-Durchwahl:	Datum:
		A/Prof.Schu/Br		04152/12 -533	September 30, 1983

Dear Dr. Tong,

referring to our good information exchange since years we would like to inform you about some of our research results obtained after shutting down the official collaboration in BWR-Pressure Suppression System Research. Based on our experimental findings we elaborated possibilities of improving the stable condensation in the case of low steam flow rate e.g. as might occur during small leak events. This effort included mitigation of dynamic load to the structure by the so-called chugging events. Enclosed please find a copy of a paper presented at 7. SMiRT-Conference in Chicago summarising some of these results. More recent findings, incorporating results from tests with collar mitigators at all vent exits were presented at the European Two Phase Flow meeting. A copy of this paper is also enclosed.

The encouraging results lead to considerations of applying similar methods of self stabilizing geometry to the GE-Mark III-PSS. A proposal of modifications is given in figures attached to this letter. We think this mitigating capability would be of some interest to you, although PSS-behavior and design are no more a crucial issue.

Sincerely yours,

Prof. Dr.-Ing. Schultheiss   Seeliger

encls.

cc: Dr. T. M. Lee, USNRC (Div. of Accident Evaluation)
Mr. McIntire, GE
Dr. Loewenstein, EPRI

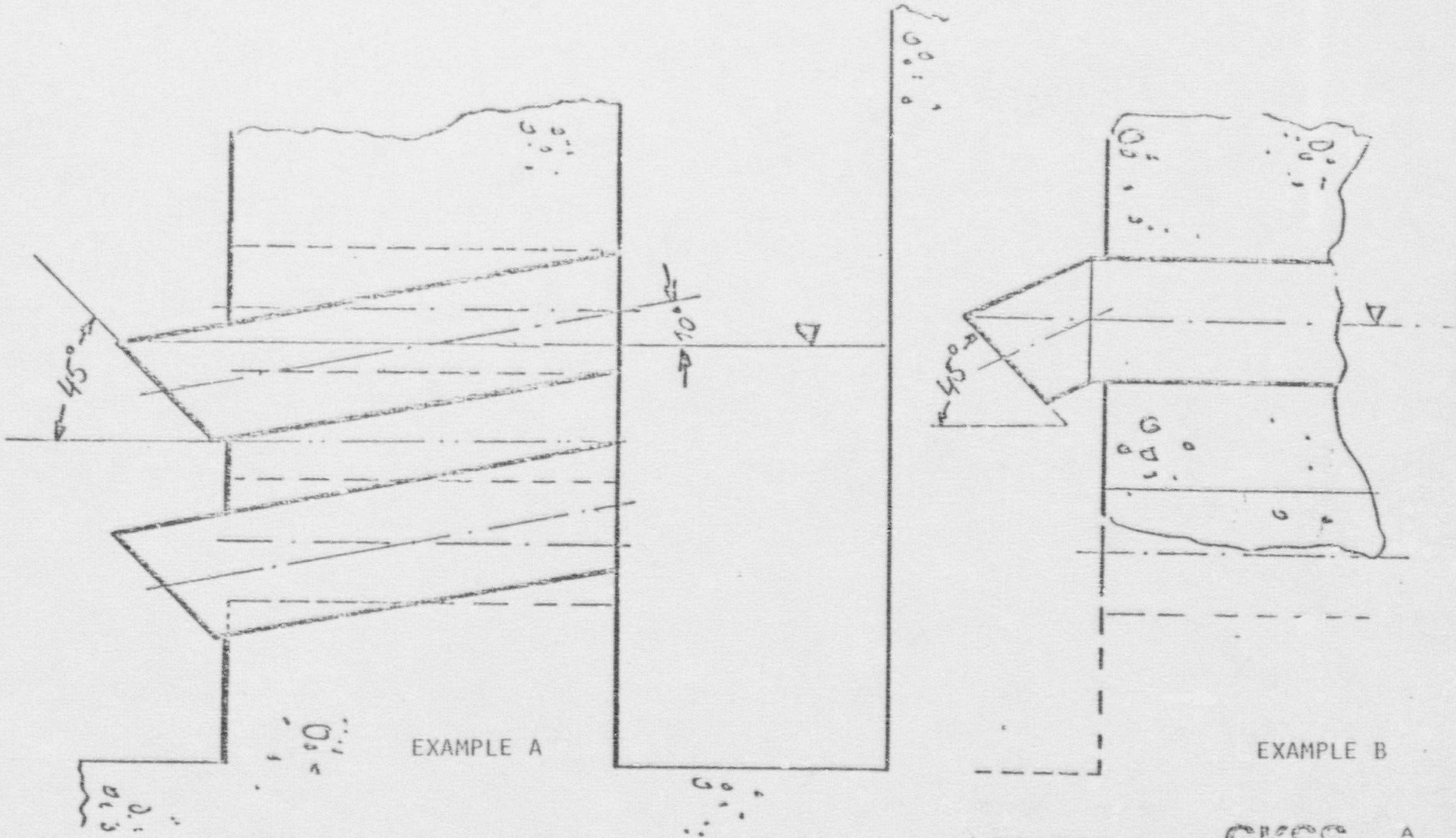
P.S.: Please transmit the attached copy to Dr. Lee.

5000 282 Ku

Rechtsform: Gesellschaft mit beschränkter Haftung, Sitz in Hamburg, Amtsgericht Hamburg HRB 7898
Vorsitzender d. Aufsichtsrates: Dr. W.-J. Schmidt-Küster, Geschäftsführer: Dr. Erich Schröder, Dr. Claus Waldherr

Leiter des Instituts für Anlagentechnik: Dr.-Ing. H.-G. Schafstall, Dr.-Ing. G.F. Schultheiss

8712110130 871203
PDR FOIA
MENZ87-160 PDR



GKSS A
FORSCHUNGSZENTRUM GEESTHACHT GMBH

GEOMETRY CONFIGURATIONS FOR IMPROVED STABILIZATION OF STEAM CONDENSATION AT LOW FLOW RATES IN GE-MARK III PSS - DYNAMIC LOAD MITIGATION

Experimental Results About Dynamic Load Mitigation for BWR-Pressure Suppression Containments Under LOCA-Conditions

E. Aust, G.F. Schultheiss, D. Seeliger
Institut für Anlagentechnik, GKSS-Forschungszentrum GmbH, Postfach 1160, D-2054 Geesthacht, Germany

E.W. McCauley,
University of California, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94550, U.S.A.

Summary

GKSS is currently conducting a pressure suppression research program in a large scale three-vent-pipe configuration, modeling main features of West German and United States BWR-pressure suppression containments.

The digital data and visual data from high-speed films of this experimental work has led to an improved understanding of the physical processes in a pressure suppression system (PSS) under loss-of-coolant-accident (LOCA)-conditions and provided basic information about the influence of key parameters on the PSS-function as well as knowledge about the reproducibility of PSS-phenomena. The experiments have demonstrated, that in addition to relatively small cyclic loads, the process produces very dynamic, periodic, steam condensation loads with characteristic impulsive pressure peaks, termed chugging.

An important engineering aspect in the ongoing program has been the studies into the potential for mitigation of such dynamic loads. Two main areas have been investigated, thermodynamic effects and hydraulic influences. Significant changes in load magnitude were obtained by varying pool temperature and pool back-pressure; in particular, an increase in initial pool temperature or final pool back-pressure was found to reduce the dynamic loads. A distinct attenuation of pressure amplitudes during chugging was also obtained by injecting air into the vent pipe, in the range of 1 % of the steam mass flow.

Study of correlated digital and visual data has clarified that the chugging process is initiated within the vent pipe near the exit, and occurs due to the implosive dynamics following the sudden condensation of the steam ring within the pipe. Based on this understanding, the most successful chug-related load reduction has been obtained by various simple geometrical changes at the vent pipe exit. The first type used a full radius collar; by modification of the fluid flow at the vent pipe outlet, chugging was eliminated. A second geometrical mitigator type used a full diameter, 45 °-exit cut; this construction modifies the mass flux to completely avoid the chugging regime and its dynamic pulses. These geometrical mitigators, in context with actual power plant construction, offer the possibility to further increase the safety margin of both present and future nuclear plants which use pressure suppression containments.

1. Introduction

The GKSS-Forschungszentrum is currently conducting a test program of applied research on a multivent BWR-related pressure suppression system (PSS). Main subjects of this reactor safety research program are to clarify the phenomena of pressure suppression processes and its dynamic loads, to provide experimental data for computer code verification, and to develop appropriate methods to reduce dynamic loads.

The GKSS test facility with its three vent pipes (Fig. 1) simulates large scale LOCA-conditions for both the German KWU type-69 and the United States G.E. MARK II-containment designs. Plant-like key values of this facility are vent pipe diameter of 0.6 m, vent pipe submergence of 2.8 m, and a pool area per vent pipe of 5.4 m². Steam provided by a flash boiler produces mass and energy release into the system to develop realistic pressure and temperature transients during LOCA-simulation /1/.

Since 1979 30 experiments have been conducted. These have provides a deep understanding of the physical processes in a PSS and improved knowledge about the PSS-function which results from varying system parameters such as mass and energy release from the steam supply system, pool back-pressure, pool start-temperature, and vent pipe submergence. In addition, clarification of the probabilistic nature of PSS-phenomena has been obtained by replication tests /2/.

An essential goal of the ongoing program was to develop, by study of the test data, possible and appropriate methods useful to mitigate dynamic loads.

2. Experimental results on dynamic load mitigation

Two methods for load mitigation were found: the first acts directly on the pressure suppression processes and the second was developed by introducing simple geometrical change in the vent pipe exit construction.

2.1 Dynamic load reduction by process engineering methods

From study of the influence of main parameters on the pressure suppression process, the pool start-temperature and pool back-pressure were identified as being of major importance for load reduction. Main results obtained from increasing the pool start-temperature over the range of 25 to 60 °C were a clear reduction of pressure amplitudes during both condensation oscillation (CO)-stage and chugging-stage. The influence of pool back-pressure was studied by varying the pressure in the range of 1 to 3 bar, obtained after air-carry-over is finished. Test results clearly showed an effective decrease in pressure amplitudes with increasing pool back-pressure /3/.

In all tests the visual data, taken during the CO- and chugging-stages, using high-speed- and TV-cameras, have shown that the pool water contains a large population of small air bubbles, vented from the drywell into the pool. This dispersed air has a large damping effect on transmitted pressure amplitudes, seen by comparing the amplitudes from the vent pipe exit with those from the pool boundary at the wetwell walls. To enhance this damping effect, air was injected near the vent entrance during the CO- and chug-phases into one and sometimes into two vent pipes, in the range of 1 % of the steam mass flow. The result of this active load reduction procedure was a distinct attenuation of pressure amplitudes during chugging /4/.

2.2 Dynamic load reduction by geometrical methods

Correlation of the optical data obtained from 1000 frame/s high-speed camera records with the pressure and temperature signals led to an improved understanding of the general physical mechanism of chugging: this phenomenon mostly appears in a stage of periodic steam mass flow inside the vent pipes with flow rates of about 10 kg/m²·s. Chugging is mainly induced by the rapid collapse of a steam annulus inside the vent pipe exit at the end of the periodic steam flow, preceeded by the condensation of in-pool steam with low pressure oscillation and vent accourtic frequency. The steam annulus collapse gives rise to a strong positive pressure peak, followed by a ringdown characteristic with the fundamental frequency of the pool-boundary system /5-6/. The steam annulus formation inside the vent pipe exit seemed to be caused by the sharp edge of the pipe exit acting as a BORDA-mouth.

These findings led to a geometrical mitigator construction consisting of a large-radius outlet collar at the vent pipe exit; the purpose was to initiate attached back flow of the pool water into the vent pipe in order to avoid the steam annulus stage with its resulting sharp pressure pulse. This construction was tested very successfully as shown in Fig. 2 and 3. It is of importance to note, that in this test only one vent pipe had the outlet collar. The result was that, while the other two vent pipes, with their normal outlet, produced the well known chugging-phenomena, no chugging occurred at the modified vent.

Another geometrical mitigator construction, even more successfully tested, worked with a 45 °-exit cut. The static pressure difference along the diagonal exit cut caused a cross flow of water and steam with a very intensive steam condensation and mixture of condensate and pool water. Most important was, that the 45 °-cut not only provided a continuous steam flow path from the vent pipe to the pool but also developed a very distinct self-regulating effect: less steam flow, less steam flow area at the exit, especially during the expected time of the chugging stage with its low mass flow rates. With this construction the two other vent pipes remained closed and all chugging was eliminated.

Calculation of the steam mass flow rate through the 45 °-cut vent pipe indicated that the critical value for chugging (about 10 kg/m²·s) was always exceeded at this vent pipe exit. Test results clearly showed that this mitigator completely avoided chugging and, as shown in Fig. 2 and 3, gave significant load reduction.

An additional effect of the dynamic load mitigation is shown in Fig. 4, where the lateral vent loads at the vent pipe exit, during a chugging-event, are presented. These forces were measured by strain gauges positioned at the outside wall of each of the braceless vent pipes. It should be noted that during a chugging event in the standard condition test the first strong force peak corresponded to the collapse of the steam ring annulus inside the vent pipe. This load caused each of the submerged vent pipe exits to oscillate in a elliptic manner with their characteristic resonant frequency.

The test with the 45 °-outlet cut vent pipe has shown that during the time for chugging, only the cut vent pipe was loaded, while the other two vent pipes received no exitation from the condensation process. It is interesting that there was no preferred oscillation direction of the cut vent pipe, for example perpendicular to the 45 °-outlet cut area. The vent pipe with collar developed no oscillation from chugging induced lateral forces, while the two other vent pipes exhibited load induced oscillations comparable to the situation in the standard test M1.

3. Conclusions

The highly efficient optical systems used in this experimental program has allowed detailed observation of the wetwell pool scene. These optical data, when correlated in time with pressure and temperature signals, have made it possible to "see" what happens in a PSS-pool under LOCA-conditions and to obtain an improved understanding of the dynamic physical processes, their related phenomena, as well as the induced dynamic loads. Based on the deep insights obtained into the general mechanism of thermal-dynamic and thermal-hydraulic phenomena at the vent pipe exit, a goal-oriented development could be initiated to produce an effective and simple geometrically based chugging-mitigator, which completely avoids dynamic loads.

The collar- and the 45 °-outlet cut-mitigator present the successful closing of this development. Because of the simplicity of these effective constructions, their application to both present and future BWR-pressure suppression containments may further enhance the safety margin of this important reactor safety barrier.

References

[1] AUST, E., FÜRST, H.D., NIEMANN, H.-R., "Basisprogramm über experimentelle Untersuchungen an Ein- und Mehrrohranordnungen für Druckabbausysteme von Kernkraftwerken, Beschreibung des Druckabbau-Versuchsstandes der GKSS", GKSS 79/E/8

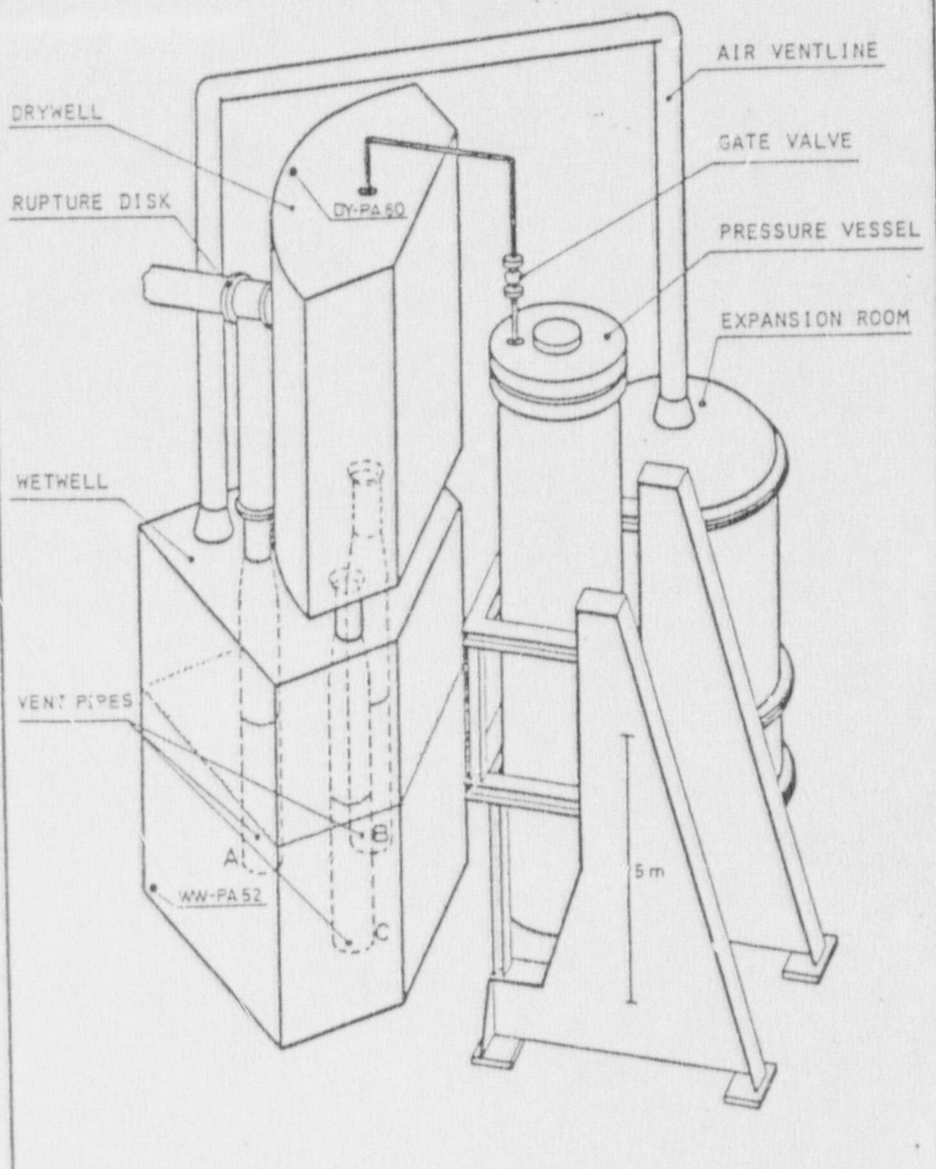
[2] McCAULEY, E.W., HOLMAN, G.S., AUST, E., "Discription of steam condensation phenomena during the loss-of-coolant-accident", Transactions of the 6th International Conference of SMiRT, Paris/France, Vol. B, Aug. 1981

[3] AUST, E., SAKKAL, F., "Review of GKSS 3-Vent Experimental Program and Results", Proc. Int. Spec. Meeting on BWR-Pressure Suppression Containment Technology, June 1-3, 1981, GKSS 81/E/27 pp. I-81 ff.

[4] SCHULTHEISS, G.F., NIEMANN, H.-R., SAKKAL, F., "Untersuchungen zur Verminderung der dynamischen Lasten bei SWR-Druckabbau-Vorgängen", Jahrestagung Kerntechnik '82, Tagungsbericht ISSN 0720-9207, p. 211-214

[5] McCAULEY, E.W., AUST, E., SCHWAN, H., VOLLBRANDT, J., and HOLMAN, G., "Physical Model of Lean Suppression Pressure Oscillation Phenomena", Transactions of the Seminar on Nuclear Reactor Safety Heat Transfer, Dubrovnik, Yugoslavia, Sep. 1980.

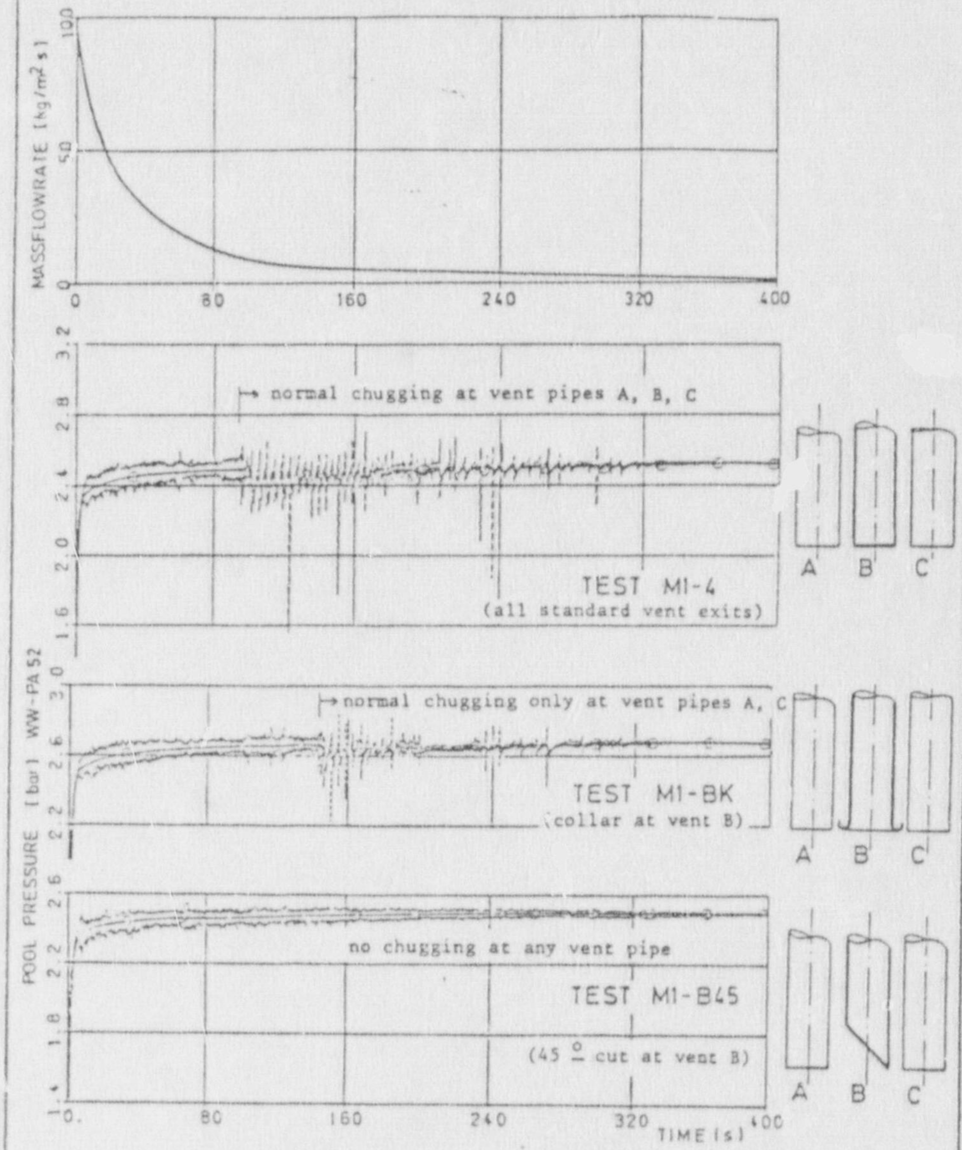
[6] AUST, E., SEELIGER, D., "Pool Dynamic and Dynamic Loads in Pressure Suppression Containment Systems", Transactions of the 1982 annual meeting, Los Angeles, California, June 6-10, 1982, Vol. 41, ISSN 0003-018X, p. 696-699



GENERAL ARRANGEMENT OF THE
GKSS PSS-TEST FACILITY

Fig. 1

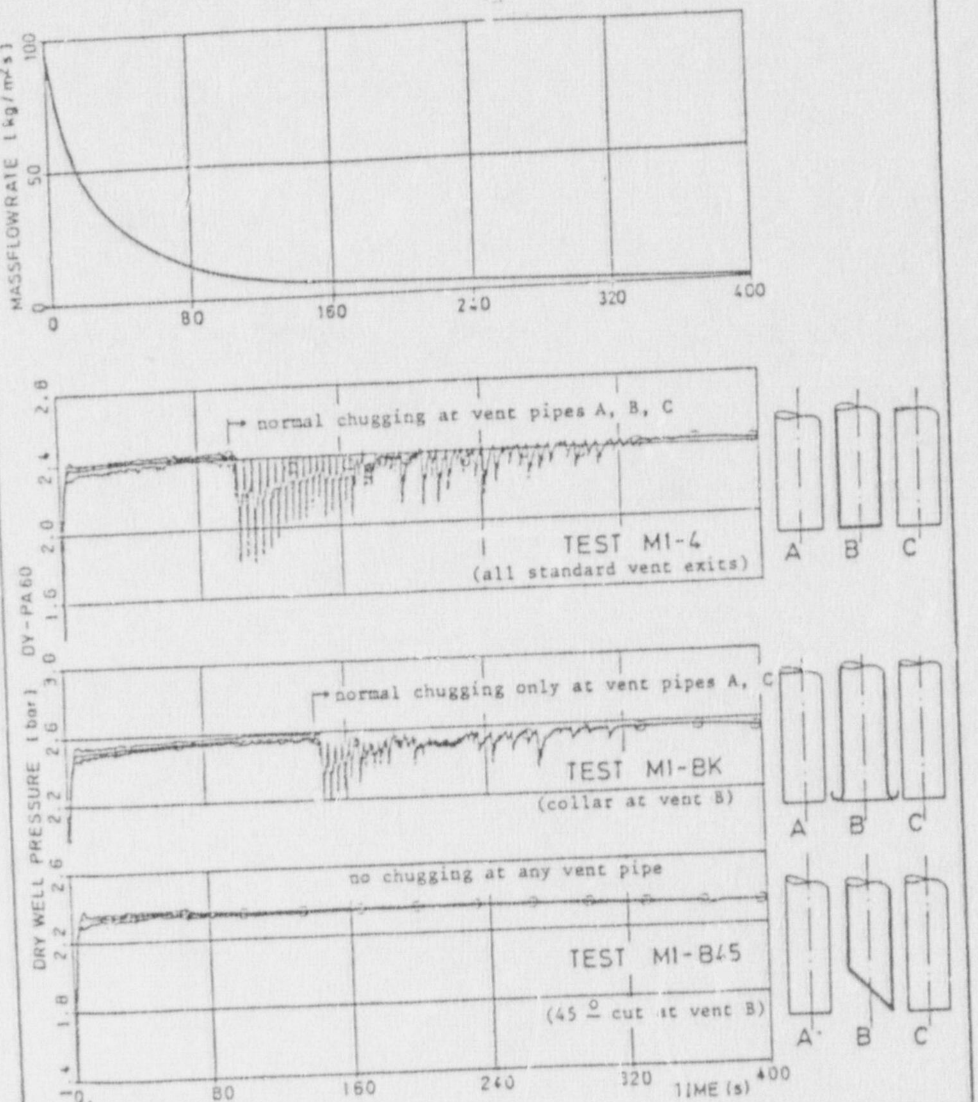
GKSS
FORSCHUNGSZENTRUM GEESTHACHT GMBH



LOAD REDUCTION BY MITIGATORS, POOL PRESSURE HISTORIES

Fig. 2

GKSS FORSCHUNGSZENTRUM GEESTHACHT GMBH



LOAD REDUCTION BY MITIGATORS, DRYWELL-PRESSURE HISTORIES

Fig. 3

GKSS FORSCHUNGSZENTRUM GEESTHACHT GMBH

J 2/1

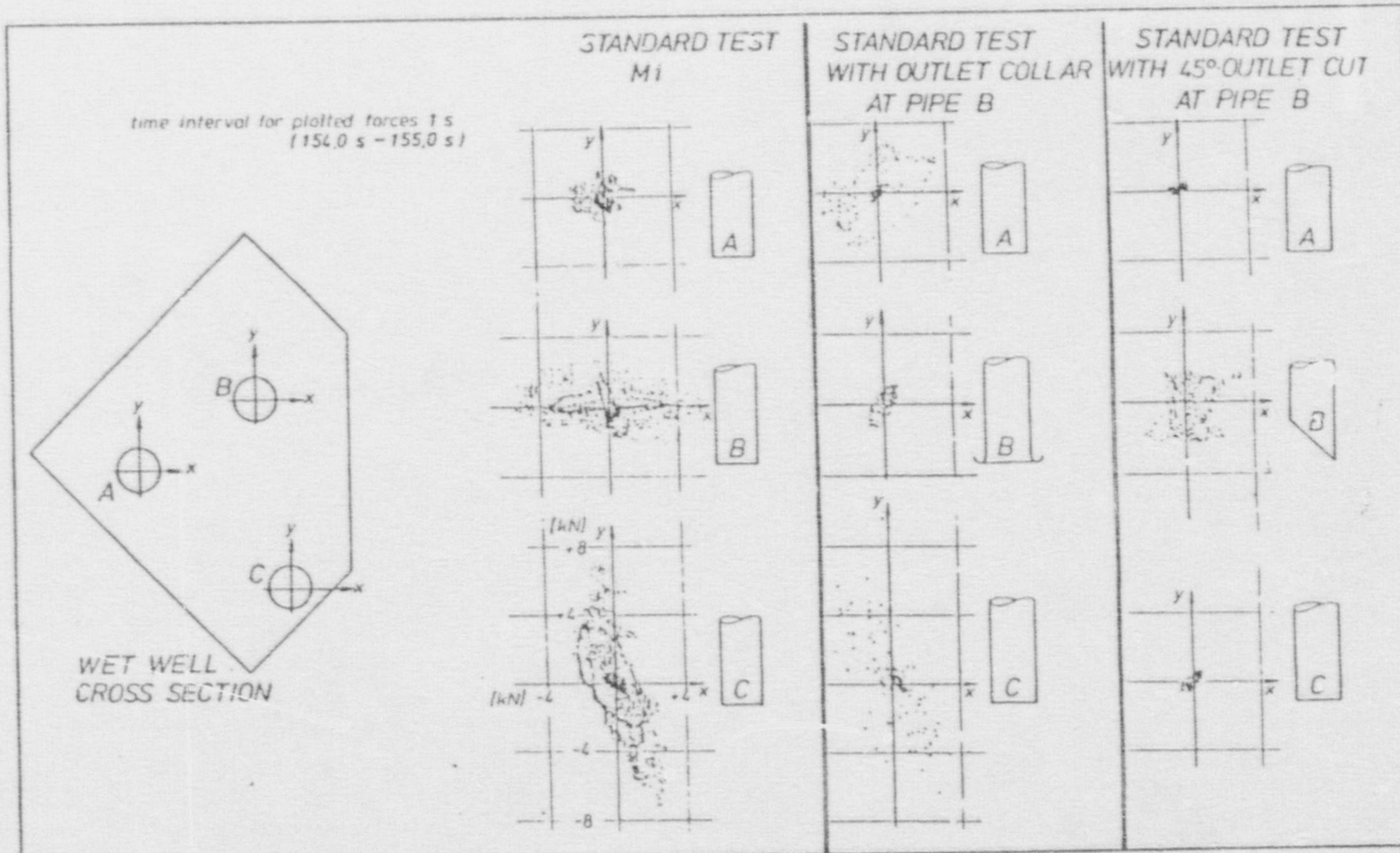


Fig. 4 LOAD REDUCTION BY MITIGATORS
LATERAL VENT FORCES DURING CHUGGING

GKSS
FORSCHUNGSZENTRUM GEESTHACHT GMBH

CONDENSATION PHENOMENA IN BWR-PRESSURE SUPPRESSION CONTAINMENTS UNDER LOCA-CONDITIONS

E. AUST, E.W. MC CAULEY,* H.-R. NIEMANN

GKSS-FORSCHUNGSZENTRUM GEESTHACHT GMBH
2054 GEESTHACHT, FEDERAL REPUBLIC OF GERMANY

1983 EUROPEAN TWO PHASE FLOW GROUP MEETING
ZÜRICH, JUNE 14-17, 1983

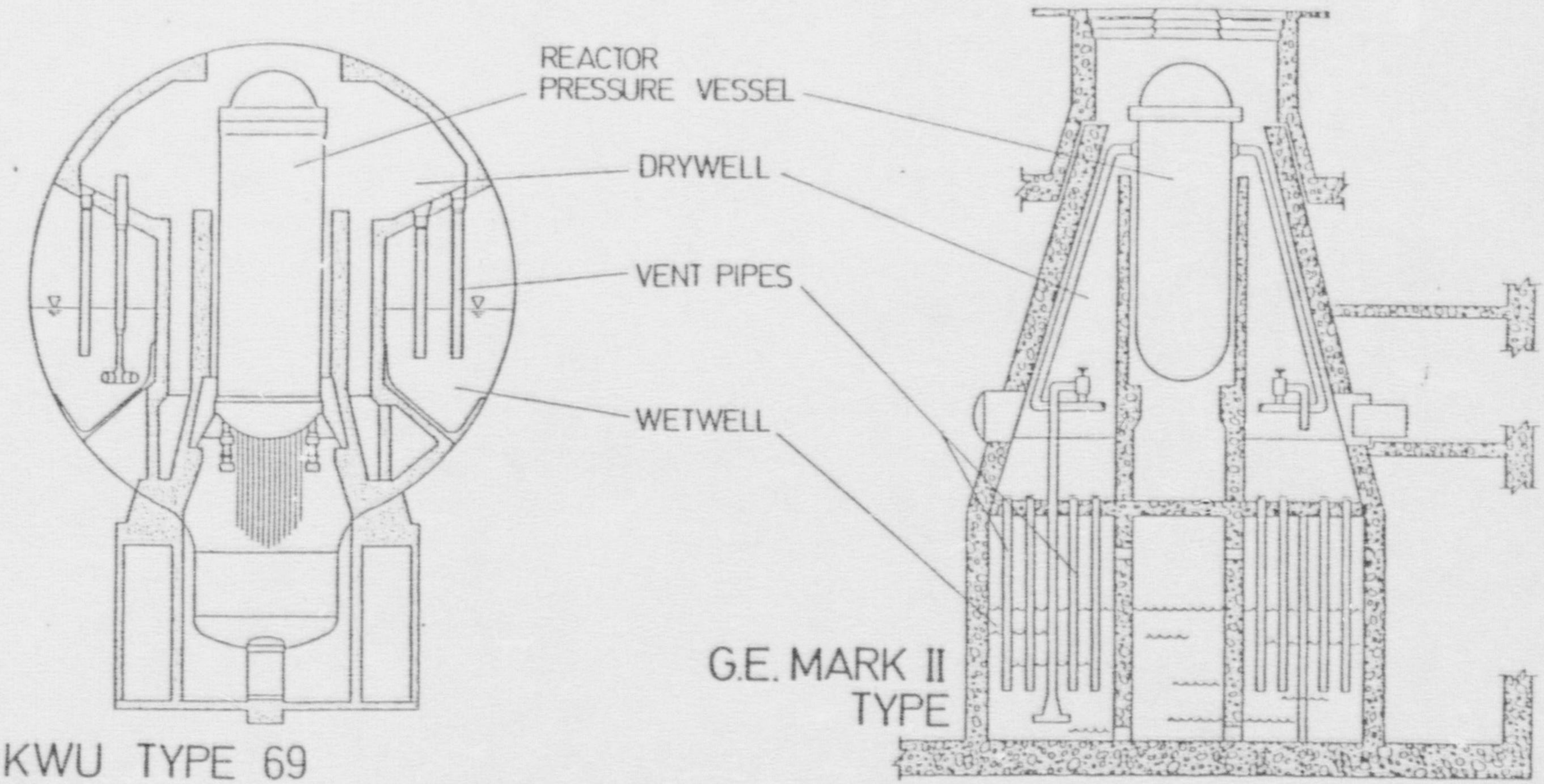
*GUEST SCIENTIST - LLNL / DOE / U.S.A.

GKSS
FORSCHUNGSZENTRUM GEESTHACHT GMBH

GKSS IS CONDUCTING GOAL ORIENTED RESEARCH ON A MULTIVENT BWR - RELATED PRESSURE SUPPRESSION SYSTEM (PSS) TO PROVIDE

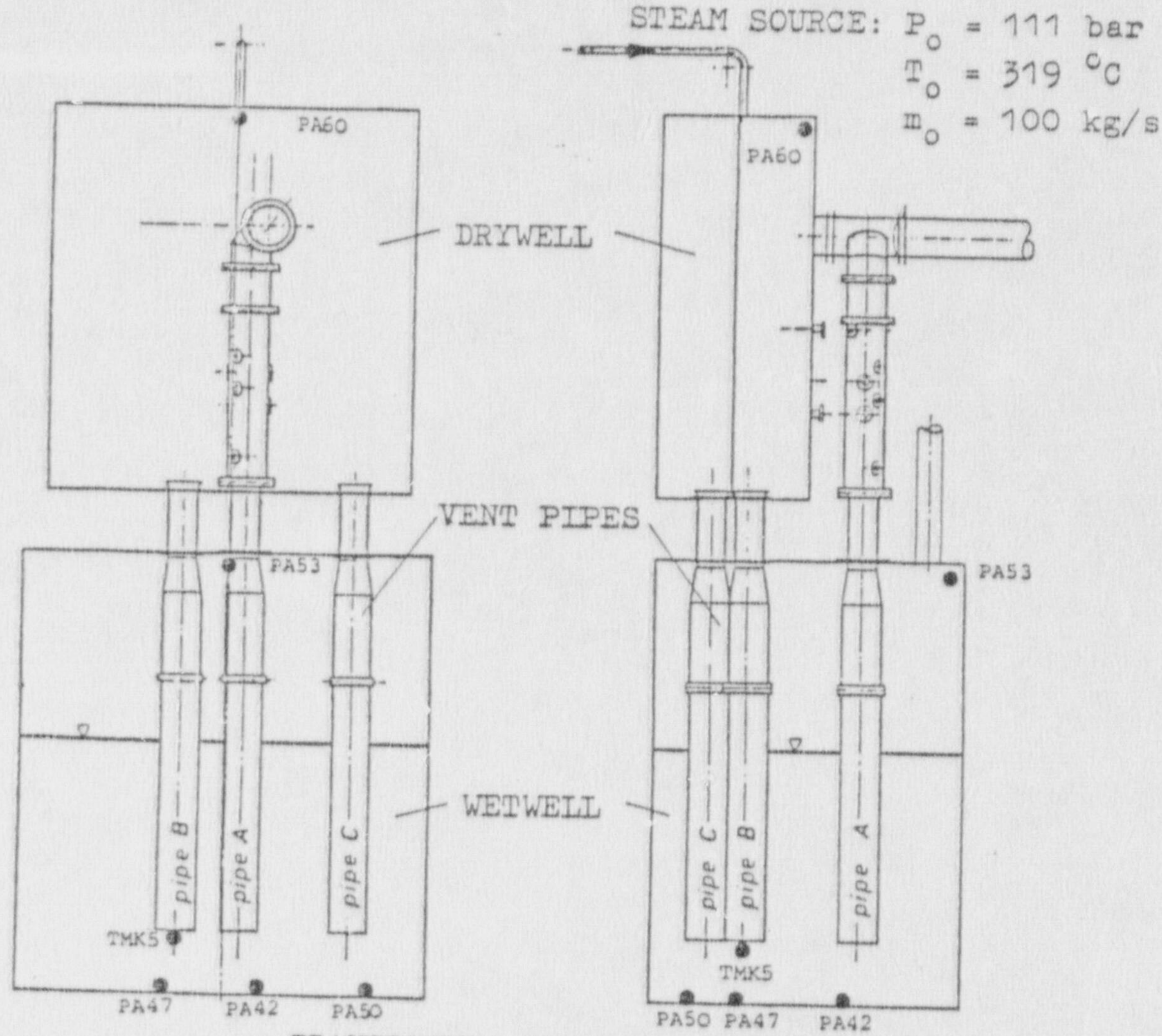
- QUANTIFIED UNDERSTANDING OF PSS - PHENOMENA
- CONFIRMATORY DATA TO DEFINE DYNAMIC LOAD FUNCTION
- RESEARCH DATA FOR ADVANCED CODE DEVELOPMENT AND VERIFICATION
- SIMPLE MITIGATORS FOR DYNAMIC LOAD REDUCTION

UNDERSTANDING OF PSS-PHENOMENA AND INDUCED DYNAMIC LOADS UNDI LOSS OF COOLANT ACCIDENTS (LOCA) IS IMPORTANT FOR PRESSURE SUPPRESSION SYSTEM DESIGN

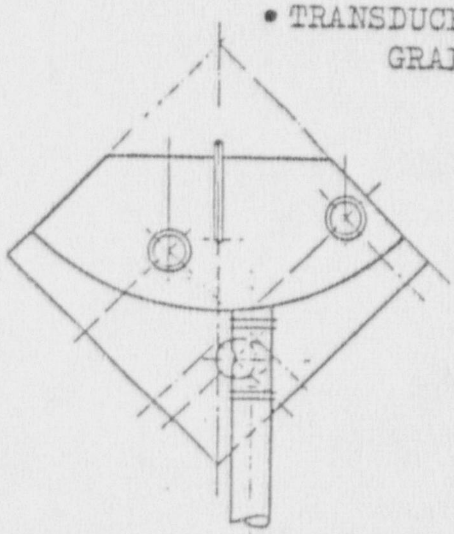


KWU TYPE 69

... TEST FACILITY CONTAINS FULL SCALE
DESIGN FOR REAL PLANT LOCA SIMULATION



• TRANSDUCERS USED IN THE PRESENTED GRAPHS: TM – TEMPERATURE
PA – PRESSURE

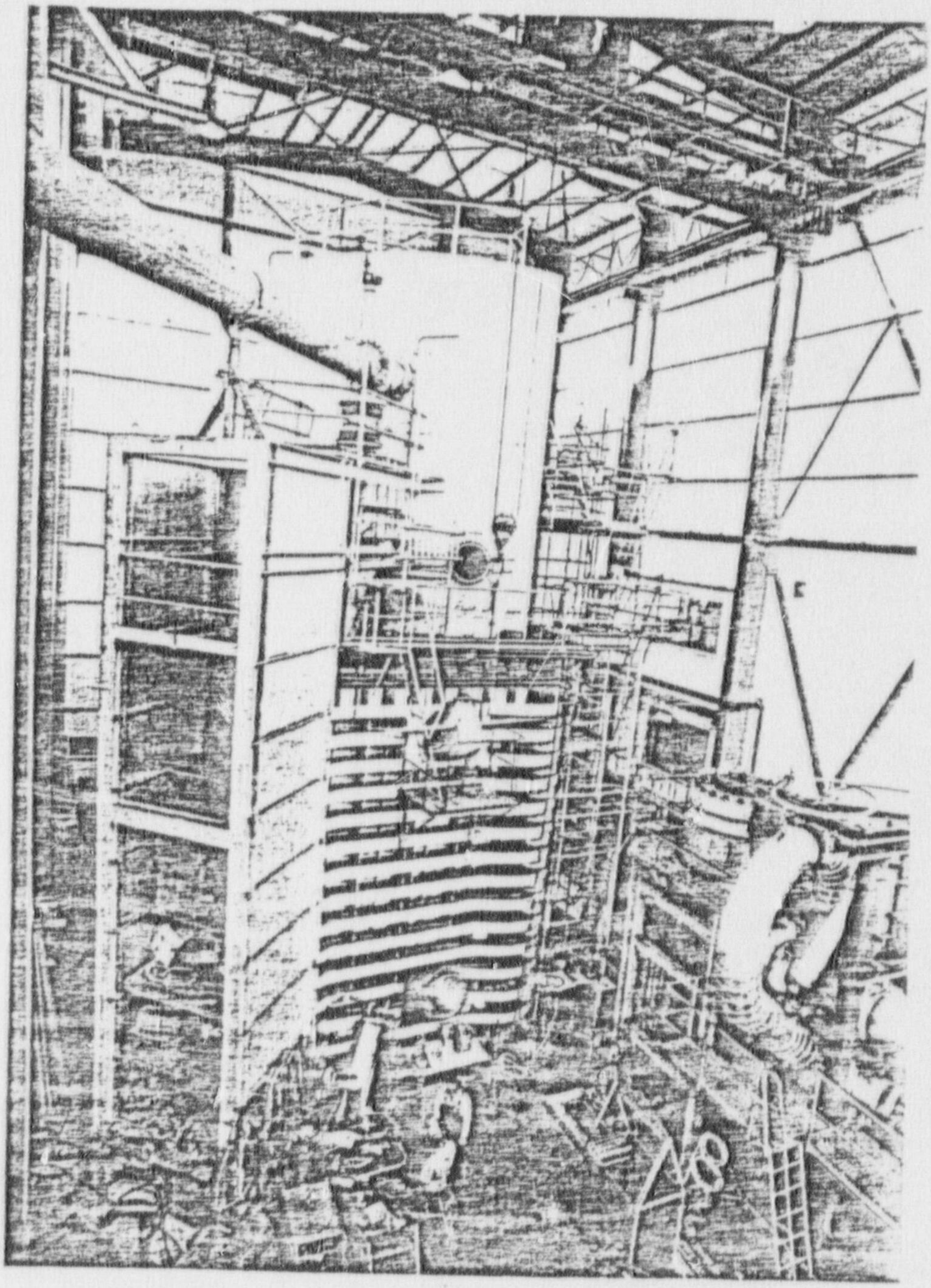


PLANT-LIKE KEY PARAMETERS

- 3 VENT PIPES
- 2,8 m SUBMERGENCE
- 0,6 m VENT DIAMETER
- 5,4 m^2 POOL AREA/VENT
- PRESSURE-TEMPERATURE TRANSIENTS

GKSS
FORSCHUNGSZENTRUM GEESTHACHT GMBH

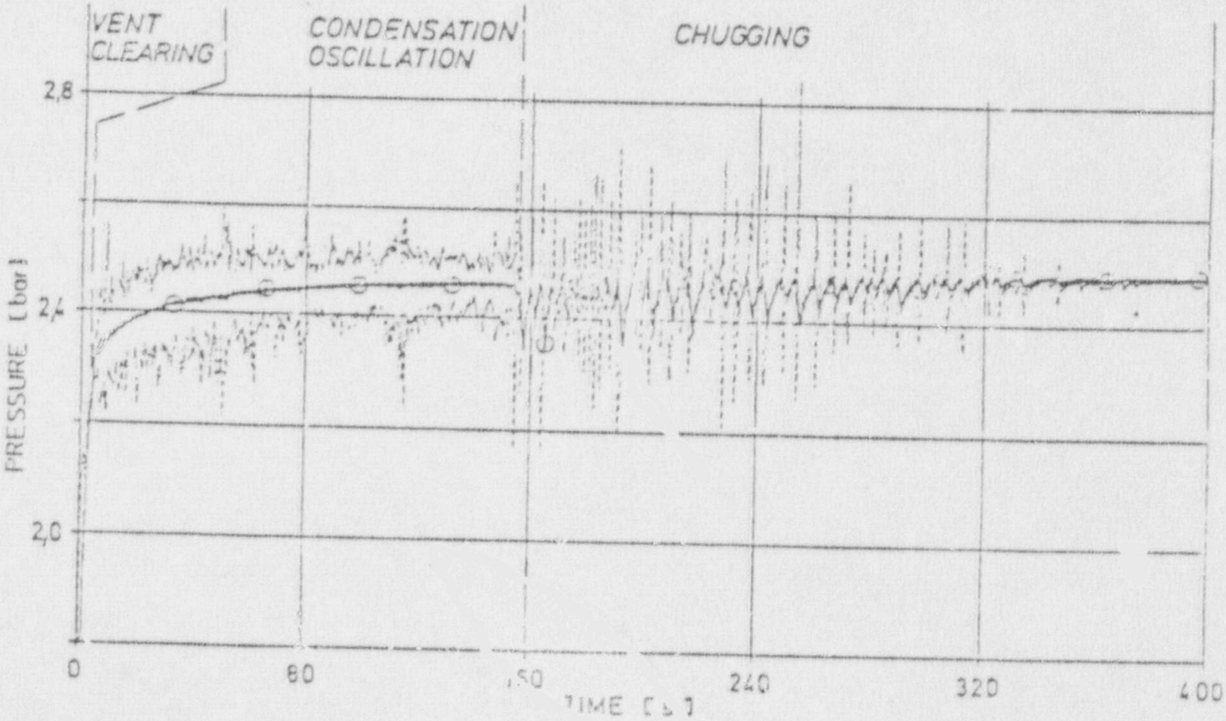
THE GKSS MULTIVENT TEST FACILITY ALLOWS LARGE SCALE PRESSURE SUPPRESSION SYSTEM RESEARCH



GKSS A
FORSCHUNGSZENTRUM GEESTHACHT GMBH

LOCA CAN BE SEPARATED INTO THREE DISTINCT STAGES

- VENT CLEARING TRANSIENT WITH A SINGLE STRONG PRESSURE PULSE
- CONDENSATION OSCILLATION WITH WEAK, CYCLIC PRESSURE OSCILLATIONS
- CHUGGING WITH PERIODIC, STRONG PRESSURE PULSES



CHARACTERISTIC WETWELL PRESSURE HISTORY
(GKSS -STANDARD CONDITION TEST M1)

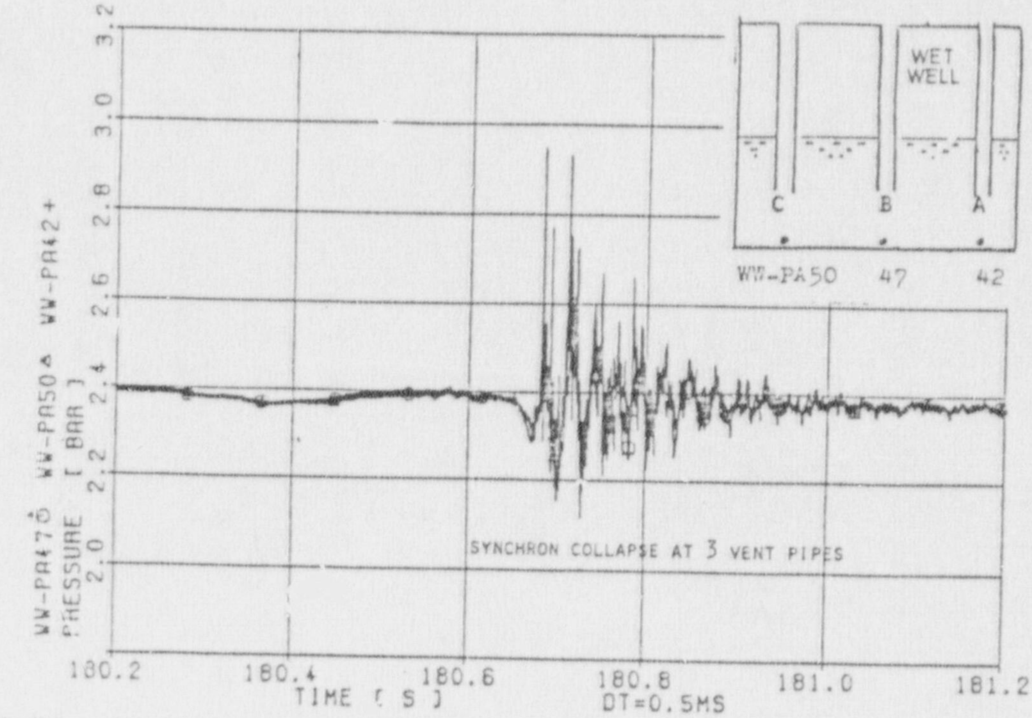
A COMPLETE MEASUREMENT SYSTEM IS REQUIRED TO INVESTIGATE SUCH COMPLEX TWO PHASE-TWO COMPONENT PHENOMENA

- DIGITAL DATA (p, Δp, T, F, ε, H, $\dot{m}$)
  - 8 ANALOG CHANNELS (40 kHz PER CHANNEL)
  - 64 PCM CHANNELS (1,7 kHz PER CHANNEL)
  - 128 DIGITAL CHANNELS (25 Hz PER CHANNEL)
- VISUAL DATA (PIPE EXIT, POOL SURFACE)
  - 3 TV-CAMERAS (50 Hz, 625 SCAN LINES)
  - 1 HIGH SPEED 16 mm-CAMERA (1000 FRAMES / S.)
- MASTER CLOCK
  - COMMON TIME LINE FOR ALL DIGITAL AND VISUAL DATA

EXPERIMENTAL STUDIES SHOW THAT CHUGGING PRODUCES THE MAJOR DYNAMIC LOADS

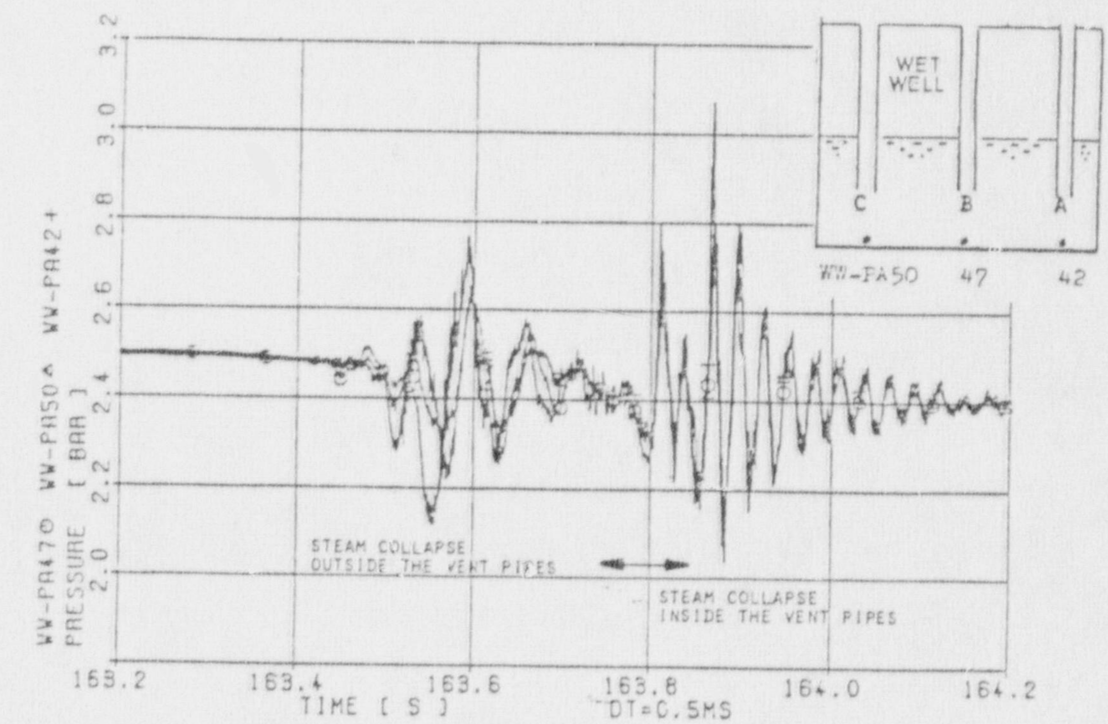
- CHUGGING EVENTS OCCUR LATE IN THE LOCA (STEAM FLUX < 10 KG/M^2S)
- CHUGGING HAS A CYCLIC NATURE (ABOUT 0,25 Hz)
- CHUGGING EVENTS ARE CHARACTERIZED BY FREQUENCY AND PRESSURE
  - VENT PIPE ACOUSTIC (12 AND 17 Hz)
  - POOL/SYSTEM RINGDOWN RESPONSE (ABOUT 38 Hz)
  - RINGDOWN INITIATED BY A SHARP CONDENSATION INDUCED RAREFACTION

THE INDIVIDUAL CHUGGING EVENTS EXHIBIT CHARACTERISTIC FEATURES



GKSS 3-VENT-TEST M 1

SINGLE CHUGGING EVENT, PRESSURE BELOW THE 3 VENT PIPES



GKSS 3-VENT-TEST M 1

DOUBLE CHUGGING EVENT, PRESSURE BELOW THE 3 VENT PIPES

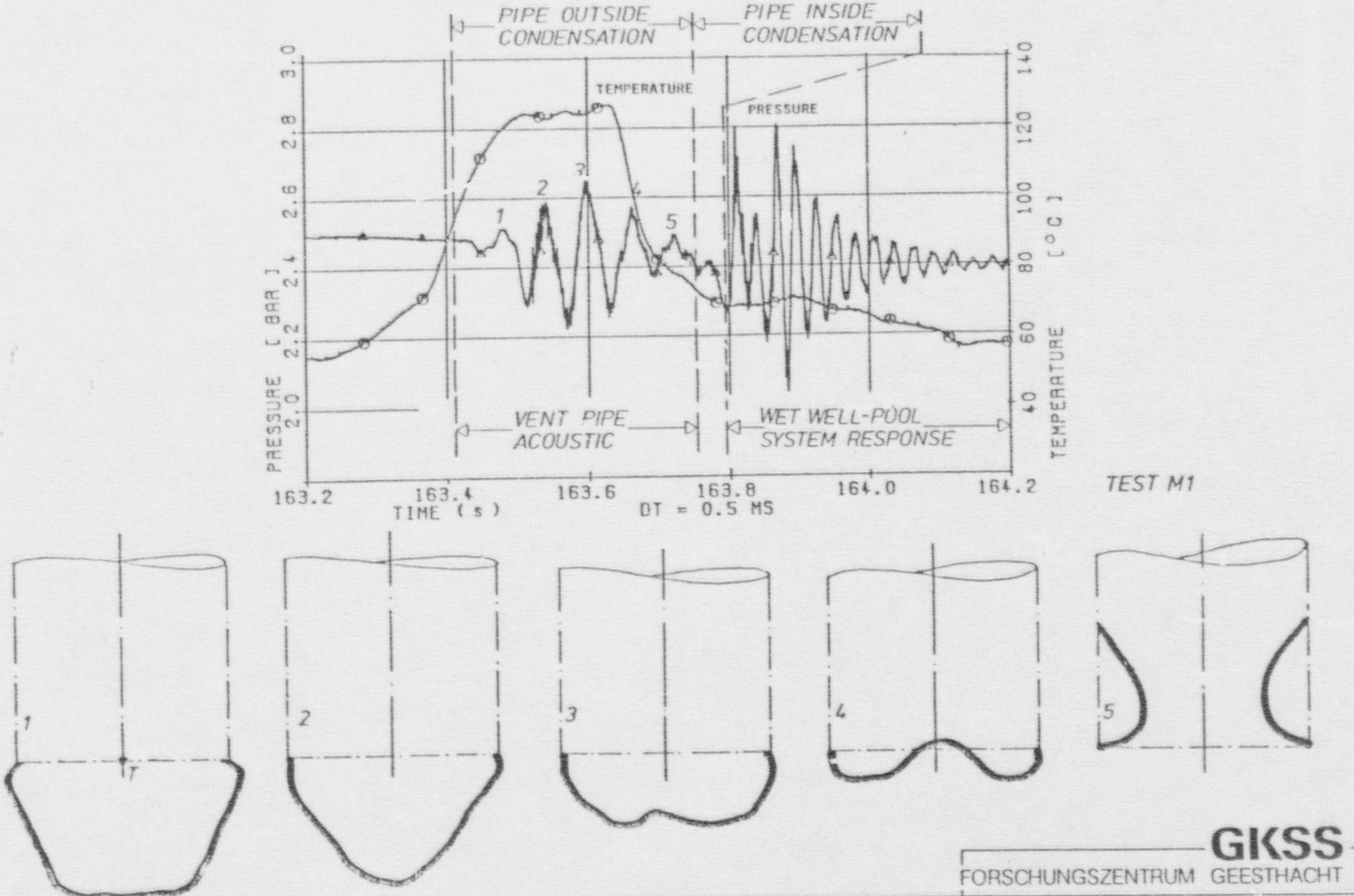
CORRELATION OF DIGITAL AND VISUAL DATA HAVE PRODUCED UNDERSTANDING OF CHUGGING PHENOMENA

- CHUGGING EVENTS ARE CHARACTERIZED BY PIPE OUTSIDE AND PIPE INSIDE CONDENSATION

- PIPE OUTSIDE CONDENSATION IS PLUME-LIKE
  - A SMOOTH STEAM CONDENSATION PROCESS WITHOUT A TRUE IN-POOL STEAM "BUBBLE"
  - SOMETIMES ACCOMPANIED BY VENT PIPE ACOUSTIC FREQUENCY

- PIPE INSIDE CONDENSATION IS RING-LIKE
  - RETREATING STEAM FRONT FORMS A STEAM RING INSIDE THE PIPE EXIT
  - CONDENSATION OF THE STEAM RING PRODUCES A RAREFACTION AND A PRESSURE PEAK
  - PRESSURE PEAK INITIATES POOL/SYSTEM RINGDOWN RESPONSE

CORRELATION OF DIGITAL AND VISUAL DATA EVIDENCE THE BASIC MECHANISM OF THE CHUGGING EVENT

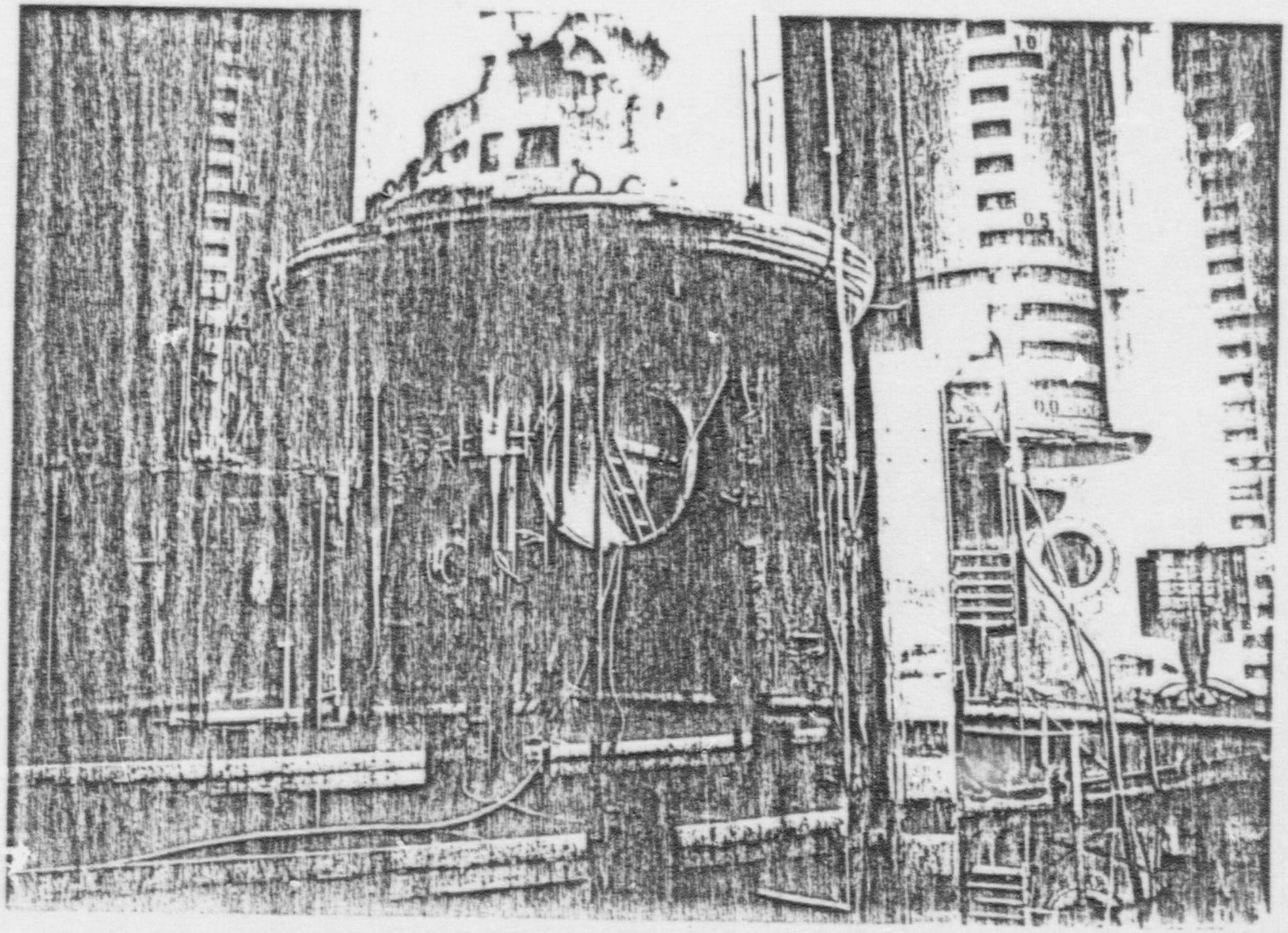


GKSS A
FORSCHUNGSZENTRUM GEESTHACHT GMBH

THE INSIGHTS GAINED INTO THE CHUGGING PROCESS ALLOW DEVELOPMENT OF SIMPLE MITIGATORS FOR DYNAMIC LOAD REDUCTION

- THE DOMINANT CHUGGING PULSE IS INITIATED BY A STEAM RING COLLAPSE INSIDE THE VENT PIPE
- STEAM RING FORMATION IS CAUSED BY THE SHARP EDGE OF THE VENT PIPE EXIT
- THE VENT PIPE OUTLET ACTS AS A WELLKNOWN FLUID CONSTRICTION, i.e, A BORDA-MOUTH
- PROVISION OF A FLOW SMOOTHING OUTLET COLLAR INITIATES ATTACHED STEAM BACK-FLOW WITHOUT STEAM RING FORMATION

FOTO OF THE 3 VENT PIPES WITH OUTLET COLLARS



GKSS A
FORSCHUNGSZENTRUM GEESTHACHT GMBH

A COMPLETE MEASUREMENT SYSTEM HAS ALLOWED DEEP UNDERSTANDING OF THE CONDENSATION PHENOMENA, TERMED CHUGGING

- TIME CORRELATION OF VISUAL AND DIGITAL DATA LED TO IMPROVED COMPREHENSION OF STEAM CONDENSATION AND THE PRINCIPLES OF TWO PHASE FLOW INTERACTION

- THE COMPLEX CONDENSATION PHENOMENON OF "CHUGGING" CAN BE REDUCED TO THE ESSENTIAL PHYSICAL MECHANISMS

- THE INSIGHTS INTO BASIC CHUGGING FEATURES ALLOW DYNAMIC LOAD MITIGATION

- A SUCCESSFUL MITIGATOR DEVELOPMENT UNDERLINES THE CORRECT INTERPRETATION OF A COMPLEX CONDENSATION PHENOMENON IN PRESSURE SUPPRESSION SYSTEMS