**NUCLEAR SAFETY QUARTERLY REPORT
APRIL, MAY, JUNE, 1967
FOR
NUCLEAR SAFETY BRANCH
OF
USAEC DIVISION OF REACTOR
DEVELOPMENT AND TECHNOLOGY**

BY
F. W. ALBAUGH, J. J. FUQUAY,
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AND D. C. WORLTON

DECEMBER 1967

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DEVELOPMENT REPORT**

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SUMMARYENGINEERED SAFEGUARDS STUDIES

J. M. Batch

Containment Systems Experiment (CSE)

Leakage rate tests of the CSE containment vessel were performed during the previous quarter at nominal leakage rate levels of 1.0, 0.5, and 0.1 wt%/day and at several pressures for each condition. Data reduction was continued this quarter. With one exception, the variation of leak rate with pressure at each of the six significant individual leak points was found to vary in accordance with laminar flow. The exception was one leak that had a leak rate greater than laminar flow theory would predict at the intermediate test pressures. This behavior was attributed to a reservoir effect of this particular leak point. A comparison was made of integrated leakage rates measured at the 60 psig maximum test pressure, and the leak rates were found by extrapolating the intermediate pressure test results by the laminar flow formula. Agreement was rather good at lower pressures: the ratio of extrapolated to observed leakage rates were in the range 0.8 to 1.4. Calculations of the integrated leakage rate were made using each individual temperature sensor, and these results were compared with the leakage rate calculated from the volume weighted average of all 19 temperature sensors. The ratio of the leakage

rate based on single sensors to that of the average varied from 0.78 to 1.55.

The first large scale fission product aerosol transport test was performed in the CSE drywell vessel to test equipment and techniques developed for the CSE containment vessel tests and to evaluate the applicability of the mathematical model of aerosol transport in condensing steam environments developed from the smaller scale laboratory work. Test conditions were held constant at 250 °F and 49 psia by steam makeup, and the test aerosol included both iodine and cesium. Test results were in good agreement with results of the mathematical model. The initial phase airborne half life was 8.0 ± 0.5 minutes. Total iodine concentration decreased from an initial $660 \mu\text{g}/\text{m}^3$ to $3 \mu\text{g}/\text{m}^3$ in the first hour, and then decreased at a slower rate to $0.2 \mu\text{g}/\text{m}^3$ after 23 hr. Cesium concentration dropped exponentially over three orders of magnitude within 90 min. Convection currents in the vessel were successfully obtained with heated thermopile type anemometers, and these data will aid materially in further development of the mathematical model of aerosol transport.

The data reduction programs developed for the gamma energy analysis system used in the aerosol transport test performed in a highly satisfactory manner. Over 700 individual samples were analyzed, and the results reported

in tabular form within four calendar days following the removal of the Maypack cluster assemblies from the drywell vessel.

Four blowdown tests were performed to evaluate the adequacy of instrumentation under conditions where the results could be reliably calculated. The tests all involved blowdown of cold water driven by pressurized nitrogen, and bottom discharge through orifices varying from 3 to 6 in. (nominal) in diameter. Instrumentation response speed was satisfactory. Results were in good agreement with predicted values for liquid weight and liquid level as functions of time. Vessel thrust measurements were satisfactory and gave results within 10% of those predicted from the jet force.

Design was completed and fabrication neared completion on a dummy core plate, flow barrel, and flow skirt. These parts will be used in blowdown tests to represent internals of pressurized and boiling water reactors. Pressure differentials and forces on these structures will be measured during blowdowns to provide more sophisticated tests of the adequacy of analytical models of blowdown.

Fission Product Aerosol Control

The study of reducing the airborne concentration of radioiodine with hydrazine sprays was continued. Four laboratory experiments were performed in a 4 ft diameter by 10 ft tall spray chamber where the hydrazine concentration and method of introduction were varied. When the results were compared with the maximum possible removal rate

for pure water, it was found that presence of hydrazine increased the removal of methyl iodide by factors between 3.5 and 7.8.

As part of the more basic problem of removing methyl iodide from the gas phase, the solution reaction rate was determined for the reaction of several reactants with methyl iodide.

PRESSURE BEARING COMPONENT EVALUATION AND MONITORING STUDIES

R. G. Wheeler

Crack Detection in Pressure Piping by Acoustical Emission

Burst testing of specimens fabricated from 3 in. diameter by 1/4 in. wall, A-106-B carbon steel pipe has provided additional insight into the nature of acoustic emission from this material. The outer surface condition of the pipe is a major factor in producing continuous emission at a readily detectable level as the metal deforms. With an "as received" oxide layer in place, the continuous emission from metal deformation is readily detectable; with the oxide removed, the continuous signal is barely detectable using gains of 10^4 . The continuous emission is apparently transmitted as a surface wave. All tests produced an abundance of transient or burst type signals with frequency content as high as 250 kHz.

Acoustic emission test data analyzed with a digital analyzer through the range of 20 kHz to 180 kHz showed a spectrum similar to that previously derived from selected data using an analog analyzer. The significant difference is the signal density in

the later data was sufficiently low that an analog analyzer showed no response.

ENVIRONMENTAL STUDIES

R. F. Foster

Columbia River Sedimentation Studies

Radionuclide analyses were completed on samples of water and suspended sediments collected from various points in the Columbia River near Astoria. The concentrations of radionuclides were quite uniform with depth except where ocean water diluted the river water. In general, samples of suspended sediments taken near the bottom contained greater amounts of radionuclides than those near the surface. The results of analyses on 90 samples of bottom sediment indicated that the concentrations of radionuclides varies widely in different parts of the estuary.

Disposal of Reactor Off-Gas into Soil Systems

On the study of disposal of reactor off-gas into soil systems, work is in progress on developing a mathematical (numerical) model for injection of gas into fractured basalt overlain with alluvium. Considerable economy for this case will result from using a variable grid spacing: a fine mesh near the injection structure where pressure gradients are steepest and a coarse grid spacing far from the structure. The computer program was altered

to accommodate the variable grid spacing, and work is progressing on obtaining the optimum node configuration.

Simulation Modeling of Thermal Generation in Selected River Systems

Prediction of temperatures that will exist in the Illinois and Deerfield Rivers after proposed nuclear power plants are in operation continued with the use of the Pacific Northwest Laboratory simulation model (mathematical). Computations of conditions downstream from the Dresden II and III plants indicate that the annual mean temperature will be significantly higher at least as far downstream as Mile 230. An extension of the study down to Illinois River Mile 80 has been started. Two thermographs were installed on the Illinois River during June to aid in a test of the computational system through the use of current data.

Geophysical Exploration of Rattlesnake No. 1 Well

Field investigation of the geophysical and hydrological characteristics of the Rattlesnake Hills No. 1 Well were begun on May 30, 1967 and completed on June 10, 1967, when the well was plugged to pretest conditions. The work proceeded smoothly and efficiently with no major difficulties encountered. Ten different wire-line logging techniques were utilized to investigate the well. In general, the information and/or samples obtained were distinct and of

high quality. Interpretation of many of the records is still in progress. However, some preliminary conclusions can be drawn at this time. Of primary

interest is the fact that the interflow zones, which were previously assumed to be volcanic tuff, are mostly weathered and altered basalt.

ENGINEERED SAFEGUARDS STUDIES

J. M. Batch

CONTAINMENT SYSTEMS EXPERIMENTS (CSE)

G. J. Rogers

Containment Leakage StudiesAnalysis of Leakage Rate Test Data

M. E. Witherspoon

One part of the CSE program of studying leakage from containment vessels has the objective of investigating the factors that affect the sensitivity and accuracy of leakage rate tests performed as part of the licensing procedure for nuclear reactors. From December 1966 to April 1967, a series of leakage rate tests with air were carried out in the CSE containment vessel at nominal leakage rates of 1.0, 0.5, and 0.1 wt%/day at 60 psig and at several lower pressures.

Leakage rate data analysis performed this quarter has been concerned with the following activities:

- Investigation of the laminar flow regime for aggregate leakage, investigation of individual leakage points, and the use of laminar flow extrapolation formulas to predict

leakage rate at elevated pressures from lower pressure tests.

- Investigation of disadvantageous temperature sampling in the containment vessel and the effect of this sampling error on the calculated leakage rate.

Aggregate leakage rate variation with pressure has been reported earlier, (January, February, March, 1967 Quarterly Report) and shows a variation close to that expected by laminar flow prediction. Similarly six individual leaks have been plotted. Each of the individual leaks showed a variation of flow rate with pressure was close to laminar flow except for one of the large penetrations that had a flow rate greater than the laminar prediction at intermediate pressures. This is attributed to a reservoir effect in the volume between seals at this leak point.

The laminar flow extrapolation formula was used at test pressures below the maximum to compare the extrapolated and actual integrated leak rates at the maximum pressure. A tabulation of the results is shown in Table 3.1 for the tests at a nominal leakage rate

TABLE 3.1. Comparison of Extrapolated and Observed Leakage Rates

Test Pressure, psig	Observed Leakage Rate, %/day	Extrapolated 60 psig Leakage Rate, %/day	Ratio $\frac{(\text{Extrapolated})}{(\text{Observed})}$ 60
60	0.14	0.14	1.0
30	0.11	0.17	1.2
15	0.06	0.20	1.4
10	0.026	0.12	0.9
5	0.013	0.11	0.8
1	0.008	0.33	2.4

level of 0.1%/day at 60 psig. The observed leakage rates are results of observations by the reference vessel method.

The agreement between the actual leakage rate at 60 psig and the rate extrapolated from data at the lower pressures is considered to be rather good. Some data have been organized to show the effect on leakage rates calculated by the absolute method if the temperature sensors were used individually, and finally, if disadvantageous locations were used. An example of some of this data at a moderate leakage rate is shown in Table 3.II.

This trend of this and other data indicates that reduced numbers of individual sensors can give a fairly adequate sample of containment air temperature as long as obviously disadvantageous combinations are avoided, such as using all bilge and wetwell sensors for an average.

Fission Product Transport Studies

Intermediate Scale Aerosol Transport Test

R. K. Hilliard, L. F. Coleman and
J. D. McCormack

The first large scale aerosol transport and containment test (Run D2.1)

TABLE 3.II. Leakage by the Absolute Method Using Individual Sensors for Temperature

Point No. Location	12/14/67 @ 1300	12/15/67 @ 1300	Δ Temp.	L%/day	Li/L avg.
1 Containment	73.16	71.70	1.46	0.245	0.85
2 Drywell	70.98	70.15	0.83	0.363	1.25
3	73.14	71.64	1.50	0.238	0.82
4 Wetwell	68.40	67.94	0.46	0.432	1.49
5 Access Way	70.11	69.41	0.70	-387	1.33
7	72.84	71.56	1.28	0.279	0.96
8	72.98	71.60	1.38	0.260	0.90
9	73.06	71.50	1.56	0.226	0.78
11 Bilge	67.47	67.11	0.36	0.450	1.55
13	73.22	71.82	1.40	0.256	0.88
14	72.0	70.66	1.34	0.267	0.92
15	73.08	71.54	1.54	0.230	0.79
17	73.08	71.64	1.44	0.249	0.86
18	71.72	70.56	1.16	0.301	1.03
25	73.08	71.60	1.48	0.241	0.83
26 Containment	73.10	71.60	1.50	0.236	0.82
28	68.42	67.49	1.43	0.249	0.86
29	72.96	71.46	1.50	0.238	0.82
30 Bilge	67.03	66.56	0.47	0.429	1.48
Average	71.67	70.47avg.	1.20	0.290%/day	1.00

was performed in the CSE Drywell vessel (Figure 3.1). Primary objectives were the evaluation of all systems and equipment as well as aerosol generation and analytical procedures related to aerosol containment tests scheduled for the 850 m³ main CSE vessel. The test was also a scale up of ADF runs (~1 m³ containment tests) by a factor of 65 to further evaluate mathematical transport models developed from ADF test data. Principal test data are tabulated in Table 3.III.

Airborne aerosol concentration within containment versus time was obtained from 7 cluster assemblies, each containing 12 individual Maypack samplers. The clusters were oriented vertically and radially within the containment vessel, (Figure 3.2) to evaluate aerosol mixing and sampling problems. Indi-

vidual air samples were taken at selected times during the 23 hr run period at a flow rate of 0.5 scfm and duration of 3 min. Samples of condensate were periodically taken from the drywell vessel sump while integrated deposition coupons were collected at the cluster assembly positions.

Ten temperature probes and nine velocity sensor systems were positioned radially and vertically within the drywell vessel as shown in Figure 3.3.

Data from the drywell, when used in transport models developed for the ADF⁽¹⁾, gave a good fit between measured and calculated values for

1. R. K. Hilliard and J. G. Knudsen. "Mass Transport Models," Nuclear Safety Quarterly Report, January, February, March, 1967, BNWL-433. Pacific Northwest Laboratory, Richland, Washington, July 1967.

TABLE 3.III. Test System and Conditions

CSE Drywell Vessel:	Height - - - - -	7.6m
	Diameter - - - - -	3.3m ₂
	Surface area - - - - -	100m
	Contained volume - - - - -	65m ³
	Area/volume - - - - -	1.54m ⁻¹
	Coating - - - - -	Phenoline 302 paint air dried 19 months
	Insulation - - - - -	none
Containment Conditions: (Natural removal, no engineered safeguards)		
	Temperature - - - - -	Isothermal 122 ± 1 °C
	Pressure - - - - -	Isobaric 3.3 ± 0.05 atm
	Steam air ratio - - - - -	1.68 mole/mole
	Condensation rate - - - - -	3.0 ± 0.1 liter/min (Steam-air replaced to maintain conditions)
	Initial aerosol concentration - -	0.66 mg/m ³ I ₂ 4.7 mg/m ³ Cs ²
Aerosol:	¹³¹ I labelled elemental iodine (volatilized)	
	¹³⁷ Cs labelled Cs ₂ CO ₃ (volatilized)

FIGURE 3.1. Containment Vessel

FIGURE 3.2. Maypack Cluster Locations

FIGURE 3.3. Locations of Velocity Sensors and Temperature Sensors

aerosol half life in containment. Early gas phase concentrations decreased exponentially with a half life of 8.0 ± 0.5 min compared with 11.5 min predicted from the ADF model. Initial slope of log airborne concentration versus time curves are primarily dependent on the gas mass transport coefficient K_g , and the vessel area to volume ratio. The curves fit a reduced equation of the type $\frac{dC_G}{dt} \approx -K_G \frac{A}{V} C_G$

where C_G , A , V , and t are gas phase concentration, vessel surface area, vessel volume, and time respectively. The ADF analytical model used steam condensation rate correlations to estimate gas convection velocities, and when actual measured velocities from the drywell containment test were used to obtain K_g , the theoretical aerosol half life in containment was 14.1 min for laminar boundary layer transfer or 8.8 min where turbulent layer transfer was assumed.

Aerosol mixing in containment was good, based on concentrations from the seven radially and vertically spaced sampler clusters. Standard deviations for samples taken 13 min after aerosol injection were $\pm 25\%$ for cesium and $\pm 15\%$ for iodine for the seven sampling locations. Sampling and analytical errors are estimated to be $\pm 15\%$.

Total iodine concentration decreased from $660 \mu\text{g}/\text{m}^3$ to $3 \mu\text{g}/\text{m}^3$ in the first hour of containment and had decreased to less than $0.2 \mu\text{g}/\text{m}^3$ after 23 hr and termination of the test. Cesium aerosol concentration dropped exponentially by three orders of magnitude in the first 90 min of containment, after which a

decrease in slope was observed. Analytical uncertainties and cross contamination problems were evidenced at later time periods and the tailing of the exponential curve may be related to these effects. Iodine was $\sim 80\%$ elemental based on silver screen activity; while cesium was greater than 99.5% particulate based on glass fiber filter activity. Twenty-five percent of the iodine activity remained on the painted surfaces after 1400 min in containment based on material balance calculations.

Convection current measurements were obtained in the 122°C , 49 psia steam air system. Maximum upward velocity was approximately 200 ft/min at the vessel centerline at test conditions, zero at $r/R = 0.2$, and downward at about 55 ft/min at 6 in. from the wall at the vessel mid-plane. The accuracy of these velocity measurements remains to be checked by calibration in the pressurized steam atmosphere used. The capability of measuring convection velocities at the above experimental conditions will prove valuable in further development of analytical mass transport models for aerosol transport behavior in containment.

Aerosol sampling hardware gave excellent performance during the test. Of the 84 individual solenoid valves in the containment atmosphere associated with the Maypack sampling systems, only one unit showed an electrical malfunction during the test. In addition, the individual Maypack sampling components showed no mechanical faults such as ruptured filters. However, severe corrosion of the stainless steel Maypack cannister was observed at regions in

contact with iodide-impregnated activated carbon granules. This latter effect is not observed with unimpregnated charcoals under the same exposure conditions.

Deposition coupons exposed for the entire CSE drywell test showed deposition characteristics listed in Table 3.IV. Deposition coupons were hung on Maypack cluster assemblies and were at ambient test temperature. Since the coupons are noncondensing surfaces as positioned in containment and were exposed to the varying aerosol concentration during the experiment, the results only typify the relative plate out characteristics of the different types of materials. Paint and silver coated surfaces have about equally high overall deposition plus retention characteristics for iodine at 23 hr, 122 °C, 49 psia steam air system conditions. Cesium in turn is absorbed primarily by steam oxidized carbon steel surfaces.

Gamma Energy Analytical System

Data Reduction

L. F. Coleman and E. L. Wells

Analysis of chemical constituents used in the containment systems tests was accomplished by gamma energy analysis of the radiochemically traced elements. The overall analytical system employed four sodium iodide detector systems and hardware interfaced to a small digital PDP-7 computer. Programs have been written to accomplish nearly all functions possible on modern multichannel analyzers and to immediately reduce the count rate data from mixed isotope systems to disintegrations per minute, with decay corrections and sample aliquot corrections applied.⁽¹⁾

- (1) *N. P. Wilburn and L. D. Coffin. The Combination of On-Line Analysis with Collection of Multicomponent Spectra in a PDP-7, BNWL-CC-700, Pacific Northwest Laboratory, Richland, Washington. July 1966.*

TABLE 3.IV. Integrated Deposition of Iodine and Cesium on Coupons^(a)

Material	Deposition, $\mu\text{g}/\text{cm}^2$ ^(b)	
	I	Cs
Carbon steel	4.8×10^{-4}	1.4×10^{-2}
Stainless steel	4.2×10^{-4}	4.0×10^{-4}
Phenoline 302	1.0×10^{-2}	3.2×10^{-3}
Silver plated copper	8.2×10^{-3}	1.4×10^{-3}

(a) Coupons are 2 1/2 in. diameter/1/16 in. thick washers.

(b) Average of seven coupon locations.

(c) Initial and final airborne concentrations were 660 and $<0.2 \mu\text{g}/\text{m}^3$ for iodine, 4700 and <0.2 cesium.

In addition to the previously reported main analytical output program to furnish radionuclide concentrations, a newly completed second program stores all analytical data on magnetic tape and a third program outputs the data in report form. The following tabulation shows the output data from one of the seven aerosol sampling locations in the previously discussed drywell test (Run D2.1). The listed results furnish airborne concentration versus time for the twelve Maypack sampling units associated with this location and the distribution of the aerosol within the Maypack components. Other report formats are furnished for other nuclides, liquid systems data, deposition data, and an averages table for aerosol concentration data at all locations.

Although only two analyzer systems were in operation when the aforementioned drywell test samples were being processed, approximately 700 samples were counted and the data reported in four calendar days at the CSE test site. One of the significant points of the whole operation is the real time programming which allows the concurrent storage of spectral data from the four, 256 channel analyzer systems in computer memory. Disintegration rate data can in turn be automatically outputted from any one of the analyzer systems without interfering with spectrum storage on the other three analyzer systems. This particular type system, interfacing several analog to digital computer (8K memory in our case), has definite advantages over several individual multichannel analyzers, each with its own data storage unit, in terms of total hardware required, space, and

the attending advantages of direct immediate data reduction plus data compilation and tabling. See Table 3.V.

Iodine-Paint Reactions

J. A. Partridge

The entire interior of the CSE containment vessel was painted with Phenoline 302. The vessel will be subjected to repeated cycles of elevated temperature, steam-air atmosphere conditions during fission product transport experiments, and interspersed with exposure to steaming and other decontaminating treatments. This treatment of the painted vessel may influence iodine behavior during CSE tests since all tests after the first will be with the steamed and aged paint. In an accident at a reactor plant, the painted surfaces inside will not have been exposed to comparable treatment. In an effort to develop information pertinent to possible adjustment of CSE test data with aged paint, a laboratory study of iodine-paint reactions has been carried on.

Analysis of the reaction products requires separation of the I_2 from organic iodides, and this was accomplished by the use of a silver catalyst trap followed by an activated charcoal trap. It was found that I_2 was sorbed quantitatively by the silver, while less than 0.01% of CH_3I was retained. Hydrogen iodide also reacts with the silver catalyst, thus making possible the separation of organic iodide from the inorganic forms HI and I_2 by this technique. Limited success was obtained in the separation of HI from I_2 using moist $CaSO_4$ (indicating Drierite).

TABLE 3.V. Run 201 Isotope I-131 Maypack Data Location Mo⁶

RUN 201 ISOTOPE I-131
MAYPACK DATA LOCATION MO6

		TOS	Filter			Screens			AC Paper			Charcoal		Total
			ug/M**3	PCT	ERR	ug/M**3	PCT	ERR	ug/M**3	PCT	ERR	ug/M**3	PCT	ug/M**3
M	1	15	0.8022-01	7.16	0.051	0.9028-02	80.63	0.009	0.5416-01	4.83	0.011	0.8247-01	7.36	0.1119-03
M	2	30	0.2309-01	5.40	0.073	0.3346-02	78.36	0.016	0.3037-01	7.11	0.017	0.3889-01	9.10	0.4269-02
M	3	40	0.1060-01	7.24	0.082	0.1171-02	80.02	0.011	0.7374-00	5.03	0.014	0.1125-01	7.69	0.1463-02
M	4	50	0.3497-00	5.61	0.087	0.4597-01	73.81	0.014	0.5115-00	8.21	0.013	0.7700-00	12.36	0.6229-01
M	5	70	0.4697-01	2.84	0.068	0.1001-01	60.62	0.011	0.1540-00	9.33	0.015	0.4492-00	27.20	0.1651-01
M	6	90	0.1023-01	0.99	0.146	0.5003-00	48.81	0.014	0.1284-00	12.53	0.015	0.3859-00	37.65	0.1025-01
M	7	150	0.2430-01	2.49	0.048	0.4863-00	49.91	0.012	0.9093-01	9.33	0.017	0.3728-00	38.26	0.9743-00
M	8	300	0.3378-02	0.55	0.111	0.1730-00	28.58	0.017	0.9466-01	15.63	0.017	0.3343-00	55.22	0.6053-00
M	9	600	0.1646-01	3.29	0.045	0.1285-00	25.72	0.014	0.6208-01	12.42	0.021	0.2925-00	58.55	0.4996-00
M	10	1100	0.1172-01	3.52	0.051	0.6614-01	19.86	0.018	0.4989-01	14.98	0.022	0.2051-00	61.62	0.3329-00
M	11	1340	0.1628-01	6.92	0.44	0.4237-01	18.00	0.022	0.6226-01	26.46	0.020	0.1143-00	48.60	0.2353-00
M	12	1400	0.1879-01	19.11	0.030	0.4460-01	45.35	0.019	0.1513-01	15.38	0.032	0.1980-01	20.13	0.9833-01

3.10

BNWL-537

When freshly painted coupons were allowed to interact with I_2 vapor at room temperature for several hours in the dark, no volatile iodide production was observed. The coupons, which had a surface area of 45 cm^2 , were in a 40 ml Pyrex container in which the initial I_2 concentration in the vapor phase was $3.7 \times 10^{-7} \text{ g/ml}$. In similar experiments where the paint and I_2 were in the presence of ultraviolet radiation, volatile organic iodide was produced in amounts representing less than 0.5% of the total iodine activity. About 95% of the total activity is sorbed on the coupon within minutes after injection of the I_2 .

For runs made at 50°C at comparable I_2 concentrations, similar results were obtained. No volatile organic iodide production was detected when the containers were in the dark. In samples under ultraviolet light, 0.5% or less of the total iodine was converted to volatile organic iodide.

Three runs with three-week-old coupons were made at 80°C with an initial amount of I_2 of about 10^{-4} g . Periodically, the entire vapor phase in each container was passed onto the system of traps mentioned above and counted. The containers were resealed and reaction between the sorbed I_2 and the paint allowed to proceed. After reaction times of from 5 to 70 hr, less than 0.01% of the total iodine activity appeared as volatile organic iodide.

Based on these results below, it appears that the extent of reaction of molecular iodine with Phenoline 302 paint to produce volatile organic iodides will be small in CSE tests.

Coolant Blowdown Studies

Cold Water, Gas Driven Blowdown Tests

R. T. Allemann, A. J. McElfresh and
R. A. Hildner

The CSE Blowdown program has the objective of evaluating the adequacy of mathematical models for analysis of the events accompanying the loss of coolant for a pipe rupture accident in a boiling or pressurized water power reactor. To this end, large scale experiments that involve the blowdown of a reactor simulator vessel are being conducted. The vessel and test stand were described in the previous quarterly report.

During this quarter, a series of tests have been performed to evaluate the performance and adequacy of instrumentation to be used in monitoring the effects of blowdowns. These four initial tests involved discharge of about 100 ft^3 of cold water by means of pressurized nitrogen gas in the upper one-third of the reactor simulator vessel. This provides a blowdown for which theoretical predictions of discharge rate can be made with confidence. Hence, the instrumentation can be exposed to transients similar to those in later blowdowns with high temperature and high pressure water.

The instrumentation arrangement (shown in last quarterly) has proved to be adequate under these conditions, and the results of the tests are in close agreement with theoretical predictions that were made by assuming adiabatic expansion of the nitrogen and orifice coefficients of 0.6 to 0.7. Figure 3.4 shows the weight of water in the vessel versus

FIGURE 3.4. Plot of Weight of Water in Vessel Versus Time After Initiation of Blowdown

time for a 600 psig and 1550 psig blowdown. Data were taken by a total weight load cell and by a time domain reflectometer⁽¹⁾ liquid level probe. Figure 3.5 shows normalized pressure data. The pressure data agree with predictions within 5% nozzle coefficients of 0.648 for a small orifice and 0.70 for a larger relative diameter orifice was used. Nomenclature for Figure 3.5 is as follows:

(1) B. E. Dozer, "Liquid Level Measurement for Hostile Environment," *Instrumentation Technology*, p.55. Feb., 1967.

P pressure (absolute)
 P_i initial pressure (absolute)
 P_o initial pressure gage
 t^* normalized time
 t time from beginning of blowdown
 C_d orifice coefficient of blowdown outlet
 A area of blowdown orifice
 M_i initial mass of water in vessel
 D_o nominal orifice diameter; actual diameters are
6 in. - 5.189 in.
4 in. - 3.438 in.
3 in. - 2.624 in.

FIGURE 3.5. Normalized Pressure Data for Four Cold Blowdowns

The weight and liquid level data agree with each other and with theoretical calculations at the high blowdown rates, but at the low blowdown rates resulting from low initial pressure and small orifice size there is a discrepancy between weight and theory. The cause of this discrepancy has not been resolved. It may be the result of a different stabilizing bar arrangement used on the early

(low pressure) runs than was used in later runs.

Thrust load cell data, measuring the reaction force of the vessel during the blowdown, has not been as accurate as desired. Dynamic effects and mounting inaccuracies have caused an unbalance of readings between two parallel load cells as well as causing readings to

differ by up to 10% from the value obtained from jet force and a free body solution of the static case. Direct calibrations of the load cells are being made to reduce this error. In addition, a stagnation pressure rake probe, placed in the issuing jet stream to measure stagnation pressures at several points across the jet, can be used to give the momentum of the blowdown jet versus time. These data will supplement the data taken from the thrust sensors.

Strain gages mounted on the simulator vessel exterior wall have shown normal strain as predicted from gas pressure by a thick walled cylinder formula. Assessment of temperature probe data is not complete. Response is fast, but the range is limited between the ambient temperature and below frost point temperature caused by the expansion of the nitrogen. Perhaps, freezing of the water film prevents the thermocouples from following the complete expansion.

Blowdowns through small nozzles have shown a discrepancy between the time when the weight and level instruments show the liquid level to have reached the nozzle and the time that nitrogen begins to blow from the vessel. The results seem to show that for blowdowns of 7 seconds or longer, the liquid level may be up to one foot above the bottom outlet nozzle when nitrogen begins to blow out. Blowout time is determined from sound recording, thrust pad cells, temperature, and impact probes. One explanation was that a hollow vortex is formed during blowdown in the relatively symmetrical arrangement of empty vessel bottom blowdowns.

A device was built to measure vorticity in the outlet pipe, but the force

of the 1550 psi discharge stream was too high and destroyed the device. The other instruments showed little or no discrepancy between liquid level and nitrogen blowout, which suggests that a hollow vortex did not have time to form during such a short (3 sec) blowdown. Further tests at lower pressures and smaller orifice sizes will be necessary to prove the reality of a vortex. The resolution of the question has value only in understanding the blowdown phenomenon and the reactor simulator vessel used as an experimental tool. It is not expected that blowdowns from upper and middle nozzles, or especially with reactor internal parts in the vessel, would form a vortex of measurable importance. This is also true for an actual reactor.

Dummy Cores and Vessel Internals for the CSE Blowdown Studies

C. H. Henager and R. T. Alleman

Work has proceeded on the design and fabrication of the dummy core arrangements to be used in the CSE reactor simulator vessel. The purpose of the design is to simulate the internal configurations of pressurized and boiling water reactors so that analytical blowdown models that predict forces and times of blowdown can be applied to a system more closely representing an actual reactor.

Discussions were held with engineering personnel of General Electric Co. and Westinghouse Corp. to obtain sizes and geometries of currently planned reactors. Table 3.VI and 3.VII list Typical area ratios and volume to area ratios being planned in PWR and BWR designs as listed in Tables 3.VI and 3.VII respectively.

TABLE 3.VI. BWR Ratios

Parameter	Outlet Break ^(a)	Inlet Break ^(a)	CSE Value ^(b)
<u>Break Area</u> Core Flow Area	0.095	0.076	0.102
<u>Break Area</u> Annulus Area	0.171	0.154	0.171
<u>Break Area</u> Upper Plenum Area	0.040	0.036	0.035
<u>Break Area</u> Lower Plenum Area	0.028	0.025	0.027
<u>Core Flow Area</u> Core Entrance Area	1.69	1.69	1.72
<u>Core Flow Area</u> Core Exit Area	1.41	1.41	1.35
<u>Core Length</u> Core Hydraulic Radius	1320.	1320.	72.
<u>Annulus Length</u> Annulus Hyd. Radius	136.	136.	107.

(a) Outlet and inlet breaks based on Indian Point 2 design. Cold leg is 27.5 in. ID and hot leg is 29.0 in. ID.

(b) CSE values based on 41.4 in. ID, 84, 2-1/4 in. Holes with 0.177 in. ID entrance inserts, 2-1/2 in. x 5 in. pipe channels, 2.00 in. exit inserts, 38.0 in. OD barrel, and 6.8 in. ID break.

Included in the tables are ratios that the CSE dummy cores will be able to reach by proper selection of blowdown size, core flow area, etc. The major discrepancy is in the ratio of the core length to core hydraulic radius. This ratio affects the friction term, which is expected to be small, although even this ratio could be matched if wires were placed inside simulated fuel assemblies to increase the wetted perimeter. The design (Figures 3.6 and 3.7) is arranged to be somewhat flexible. Turning the barrel nozzle away and toward the blowdown nozzle will simulate the PWR inlet

and outlet breaks respectively. The BWR arrangement will allow blowdowns simulating single ended breaks of steam line or recirculating water lines.

Most of the current analytical models consider the reactor as a number of chambers and flow resistance as essentially in series. Complications such as parallel flow paths and complex flow restrictors, such as nozzle orifice, can be added, and simple area changes can be made in whatever detail is desired as experimental results are obtained.

Work has begun on the base plate that will be used as an adjustable area septum

TABLE 3.VII. BWR^(b) Ratios

Parameter	Outlet Break	Inlet Break	6.8 in. Break CSE	4.5 in. Break CSE
<u>Break Area</u> Steam Plenum Area	0.0107	0.0124	0.0270	0.0118
<u>Break Area</u> Core Flow Area	0.0442	0.0513	0.119	0.0522
<u>Break Area</u> Annulus Flow Area	0.0355	0.0412	0.0925	0.0405
<u>Break Area</u> Jet Pump Area	0.528	0.613	1.202	0.527
<u>Break Area</u> Lower Plenum Area	0.0181	0.0210	0.0452	0.0198
<u>Break Area</u> , ft ⁻¹ Total Water Vol.	0.334 x 10 ⁻³	0.387 x 10 ⁻³	3.30 x 10 ⁻³	1.205 x 10 ⁻³
Volume Fraction In Annulus	0.462	0.462	0.291	0.291
Volume Fraction In Core	0.175	0.175	0.238 ^(a)	0.238 ^(a)
Volume Fraction In Lower Plenum	0.362	0.362	0.471	0.471
<u>Core Flow Area</u> Steam Sep. Exit Area	3.75	3.75	3.49	3.49
<u>Core Flow Area</u> Core Entrance Area	3.20	3.20	2.38 ^(b)	2.38 ^(b)
<u>Core Flow Length</u> Core Hyd. Radius	1164.	1164.	95.7	95.7
<u>Annulus Length</u> Annulus Hyd. Radius	59.2	59.2	45.5	45.5
<u>Jet Pump Length</u> Jet Pump Hyd. Radius	100.8	100.8	85.4	85.4
<u>Break Area</u> Stm. Dries Area		N/A		

(a) Ratio adjustable by simple modifications.

(b) Based on Browns Ferry proposed design values.

FIGURE 3.6. Pressurized Water Reactor Simulation in CSE

FIGURE 3.7. Boiling Water Reactor Simulation in CSE

between the upper and lower reactor volumes. Additional parts will be mounted on this base plate as the complexity of the experiment dummy core increases. Vertical forces on the core will be measured by strain bolts that secure the core plate to the vessel. Pressure transducers will be located on each side of the core. Radial or horizontal forces will be measured by means of transverse profiles and strain of simulated control rods.

FISSION PRODUCT AEROSOL CONTROL

L. C. Schwendiman, L. L. Burger

Removal of Organic Iodides with Reactive Sprays

L. C. Schwendiman, J. Mishima, and
A. K. Postma

When a serious reactor accident occurs, volatile and gaseous fission products are released to the containment volume. A possible method of reducing the airborne concentration of radioiodine and its compounds is to immobilize them by adding a reactive compound, such as hydrazine, to sprays. Research is underway to establish the incentives and conditions for utilizing additives to reactor sprays.

The objectives during the current quarter were to further demonstrate the effectiveness of hydrazine sprays and to help establish the conditions favoring effective removal.

Four more spray demonstration experiments were completed in the 4-ft diameter by 10-ft tall (3.6 m^3) spray chamber. The essential results of these experiments are shown in Table 3.VIII.

In experiment HS-3 conditions were maintained similar to conditions for run HS-2⁽¹⁾, except that the concentration of hydrazine was raised from 6% to 8.6%. This change affected the removal rate insignificantly. A half-time of removal of 60 min was realized.

In experiment HS-4 hydrazine solution was sprayed down the wall at a rate equal to that flowing down the wall during spraying with the same nozzle used in HD-2 and HS-3. The hydrazine solution was introduced through a wall washing ring at the top of the chamber: hence conditions were not identical to the wall washing while using the spray nozzle. Hydrazine concentration was about that used in HS-2, 6%. This solution delivered to the wall proved to be about as effective volume for volume as that delivered by the spray in previous experiments. When the same flow was delivered to the wall through the washing ring (HS-6) as was sprayed (2.5 gpm), the half-life of removal was about 75 min. Thus, removal rate was somewhat slower than for an equal flow through the spray nozzle. The wall area was roughly 2-1/2 times the total spray droplet area existing at one time.

A lower spray rate of hydrazine was used in experiment HS-5. Reducing the spray rate to 1/3 of that for previous experiments effectively doubled the half time for washout.

The relative merit of hydrazine in these experiments may be determined by

(1) L. C. Schwendiman and L. L. Burger. "Removal of Organic Iodides with Hydrazine Sprays," *Safety Quarterly Report* January, February, March, 1967. BNWL-433. Pacific Northwest Laboratory, Richland, Washington.

TABLE 3.VIII. Summary of Data of Hydrazine Spray Demonstration Runs
(3.6 m³ Stainless Steel Spray Chamber)

	Run Designation			
	HS-3	HS-4	HS-5	HS-6
Atmosphere:	Air-steam	Air-steam	Air-steam	Air-steam
Methyl Iodide Concentration, mg/m ³	0.09	0.09	0.09	0.09
Spray Composition: % hydrazine	8.6	5.8	5.6	5.9
% ammonium hydroxide	~5	~5	~5	~5
Spray Volume (recirculated volume), liter	46.5	26.5	25	50
Nozzle	Bete fog nozzle	(a)	Bete fog nozzle	(a)
Spray Drop Size Distribution, μ	120-750	--	120-750	--
Spray Flow Rate, gpm	2.5	1.12	0.7	2.5
Duration of Run, min	240	240	240	240
Chamber Temperature, °C: at start	92.5	98	91	93
at end	45	35	38	40
Distribution of Active Methyl Iodide Recovered: Spray Liquid	89.2	68.5	71.3	86.6
Airborne	10.8	31.5	28.7	13.4
Half-Time for Removal, min	60	135	120	75

(a) Wetted wall experiment

comparing the half time for washout with hydrazine under the experimental conditions with the estimated removal half time that would have been achieved had pure water been used. The assumption is made that had water in the same flow been used, the methyl iodide would have achieved the equilibrium concentration in the water during the time of passage through the tank.* It is apparent that

this would be the ultimate removal rate for pure water.

The change in air concentration, which would make the above simplifying assumption of equilibrium solubility time, is expressed by the following equation:

$$C_g = (C_g)_o \exp - \frac{KLt}{V}, \quad (1)$$

in which

C_g = concentration of methyl iodide in air at time, t

$(C_g)_o$ = initial concentration of methyl iodide in air

K = the partition coefficient

L = volume rate of liquid

V = volume of the tank.

The half-life of removal would be

$$T_{1/2} = \frac{(0.693)(V)}{KL} \quad (2)$$

* Griffiths showed that absorption equilibrium for iodine between air and 500 μ water droplets would be attained at 100 °C in about 170 cm free fall. It is tenable that methyl iodide should reach equilibrium between air and water droplets of the size used in these experiments during passage through the 10 ft fall in this spray chamber. See "The Removal of Iodine from Atmospheres with Sprays," by V. Griffiths, AHSB (S) R45.

In Table 3.IX removal half-times for the experiments to date are compared with those estimated had one-pass water alone been used. A distribution coefficient of 1 was used corresponding to a liquid temperature of about 47 °C.

TABLE 3.IX. Comparison of Removal Half-Times for Hydrazine Spray and an Equal Flow of Water

Run Designation	T _{1/2} N ₂ H ₄ , hr	T _{1/2} Water, hr	Ratio
HS-1	2.0	15.5	7.8
HS-2	0.92	4.35	4.7
HS-3	1.0	4.35	4.3
HS-4	2.25	9.72	4.3
HS-5	2.0	15.5	7.8
HS-6	1.25	4.35	3.5

These experiments continue to show that recirculated hydrazine sprays of the concentrations and drop sizes used are definitely effective in removing methyl iodide from air-steam atmospheres.

The removal half-times, though significantly shorter than for water, are not nearly as short as those predicted for the situation in which the absorption is controlled by the gas phase mass transfer resistance. The washout rate of iodine with sprays containing sodium thiosulphate, considered to be a "reactive" compound, is usually calculated on the assumption of negligible mass transfer resistance in the liquid phase. This limiting case is attained only for extremely rapid reaction liquid phase reactions. The rate of the solution reaction between methyl iodide and hydrazine, though rapid when compared with many organic chemical reactions,

is relatively slow when compared to the reactions that would be required to eliminate the liquid phase mass transfer resistance for falling drops of reasonable size. Thus, a suitable washout model for methyl iodide will have to account for the finite reaction rate in the liquid phase.

In addition to the washout by falling drops, the absorption by the liquid film on the wall must also be considered. Typically, about half of the sprayed liquid impinges on the wall, which presents a surface area greater than the area of the falling drops of relatively coarse sprays.

We are presently developing a model to describe the absorption, by accounting for chemical reaction in both the drops and the wall film. For stagnant drops, equations for absorption with chemical reaction have been published. These equations will be evaluated numerically for a range of drop size, reaction velocities, and exposure times. A prediction of the total absorption by a given spray can then be made. Absorption with chemical reaction in a thin laminar film has not yet been satisfactorily treated. Hence, we are required to solve the basic differential equation that describes absorption with chemical reaction in a laminar film. It is likely that a numerical solution employing a computer will be required.

The model briefly described above represents a more simple physical situation than that actually occurring within the spray tower. Most notably, we have neglected turbulent mixing processes that could occur both within the drops and the wall film. However, for the range

of conditions employed, the transfer processes are not expected to be governed by turbulent mixing.

One test of the model has been made, and this was made for a case in which a negligible portion of the spray impinged against the wall. The washout rate predicted for the falling drops was in good agreement with the measured removal half-time.

With measured liquid phase reaction rates and partition coefficients available, the hydrazine-methyl iodide system appears to be an excellent one to establish the validity of reactive spray models that account for a finite reaction rate.

Higher temperatures and pressures than those attainable in the 3.6 m³ spray chamber are desirable to simulate those conditions immediately following a reactor accident. The applicability of one of the vessels used in the CSE simulant development test (ADF) was studied for these experiments. Experiments showed that the ammoniacal dilute hydrazine solutions considered for use are no more detrimental to the phenoline paint than water at the temperatures and pressure to be used. Design was completed and fabrication was underway to prepare the vessel for use.

Basic Chemistry of Methyl Iodide and Reactive Spray Systems

L. L. Burger and R. A. Hasty

The objective of this study is to determine the mechanisms and rate of reaction of methyl iodide with hydrazine and other additives as part of research to find compounds that will remove methyl iodide from the gas phase. In earlier

studies the removal of methyl iodide from a gas phase in contact with an alkaline hydrazine solution was examined in detail, and a model that was successful in fitting the bench-scale data was proposed. The results of this effort through December, 1966 were reported in BNWL-SA-821. A technique that was used to determine the solution reaction rate of methyl iodide was tested. A description of this technique was presented in the January, February, March, 1967 Quarterly Report.

Solution Reaction Rates

During the current reporting period the solution reaction rate was determined for the reaction of several reactants with methyl iodide. When a large excess of reactant compared to the amount of methyl iodide was used, the data that are obtained can be treated as though the reaction were a first-order reaction. Presented in Table 3.X. are some of the reaction rate constants as determined for the reaction approximately at 21 °C.

Partition Coefficient of Methyl Iodide

The partition coefficient of methyl iodide between the gas phase and an aqueous solution was determined between 4.85 °C and 68.5 °C. A gas chromatographic technique was employed to determine the gas phase concentration of methyl iodide, which varied from 0.64×10^{-8} to 2.8×10^{-7} g-moles/liter. The aqueous concentration of methyl iodide was estimated by a material balance of the amount of methyl iodide introduced to the system.

TABLE 3.X. Reaction Rate Constants

Description of Solution	Observed Half-Life, min	Pseudo-First Order Rate Constant, min ⁻¹	Second Order Rate Constant, liter m ⁻¹ sec ⁻¹
0.64 wt% N ₂ H ₄ in 0.0235N HCl	33.7	2.1 x 10 ⁻²	1.7 x 10 ⁻³
0.64 wt% N ₂ H ₄ in 0.0255N NaOH	1.7	0.41	3.4 x 10 ⁻²
0.09N Na ₂ S ₂ O ₃	4.2	0.165	3.1 x 10 ⁻²
0.007N Na ₂ S ₂ O ₃	57	0.012	2.6 x 10 ⁻²
0.09N KIO ₃	30-270 ^(a)	≤0.023	≤2 x 10 ⁻²
0.0504N NaOH	4.4 x 10 ³	1.6 x 10 ⁻⁴	5.3 x 10 ⁻⁵

(a) Considerable scatter of data, so that an upper and a lower-limit of the half-life was estimated.

The partition coefficient [(g-moles CH₃I/liter, liquid)/(g-moles CH₃I/liter, vapor)] was found to be approximated by the relationship

$$\log(\text{partition coefficient}) = -4.82 + \frac{1597}{T(^{\circ}\text{K})} \quad (3)$$

The data deviates from this linear relationship above 30 °C. That is, a possitive deviation at 45 °C of approximately 20% with respect to the equation and a negative deviation at temperatures above 60 °C is indicated (Figure 3.8).

No effect of concentration was found from 6.4 x 10⁻⁹ g-moles/liter to 1.28 x

10⁻⁷ g-moles/liter at 29.9 °C. However, the value of 2.75 ± 0.20 for the partition coefficient at 29.9 °C, that was found in this work, differs significantly from the value of 4.0 that is calculated from the data reported by Glew (Discussions Faraday Soc. 1953, 150) for solutions with approximately 10⁻² moles CH₃I/liter).

Definition of partition coefficient as a function of temperature and measurement of reaction rates permitted the relative effectiveness of hydrazine sprays to be determined and provided input needed for determining the validity of spray removal models.

FIGURE 3.8. Partition Coefficient for Methyl Iodide as a Function of Temperature

PRESSURE BEARING COMPONENT EVALUATION
AND MONITORING STUDIES

CRACK DETECTION IN PRESSURE PIPING
BY ACOUSTICAL EMISSION

P. H. Hutton, H. N. Pedersen, and
J. C. Spanner

Introduction

The capability to detect and locate flaw formation and/or growth in reactor pressure systems on a continuous monitor basis is of prime interest as a means of enhancing nuclear safety. Development of a system to perform this function by detecting acoustic emission (pressure waves) generated in metals as they deform or fracture is in progress at the Pacific Northwest Laboratories. The program is sponsored by the Division of Reactor Development and Technology, USAEC. Activity on the program began in February, 1966 and is currently scheduled for completion by July, 1969.

The initial phase of the program was devoted to gaining an understanding of the general acoustic emission response of the materials of interest and evaluation of field application problems. Primary emphasis is now being placed on signal analysis and characterization in terms of metallurgy and material, and on development of a high temperature sensor. The final part of the program will be directed to demonstration of the technique in the field.

Discussion

Several static burst tests have been performed using small pressure vessels

fabricated from 3 in. diameter x 1/4 in. wall, A-106-B carbon steel pipe. The specimens have been tested in three conditions - "as received" annealed, sand-blasted outer surface, and sand-blasted outer surface with subsequent heat and quench treatment to embrittle the material. A through-wall crack flaw with an inside seal patch was used in all the tests except one, where a 75 % through, milled flaw with an inside patch was used.

Typical acoustic emission responses observed from the above tests are shown in Figures 4.1, 4.2, and 4.3. The effect of surface condition in producing readily detectable continuous emission relating to deformation is evident in these illustrations. The continuous signal buildup during the last 10 sec prior to failure in Figure 4.1 is attributed to deformation. The burst test data shown in the January, February, March, 1967,) Quarterly Report shows an even more pronounced continuous signal buildup prior to failure. The pipe specimen used in both of these tests was in the "as-received" condition: the oxide layer in place. Figure 4.2 shows the data from a similar test where the oxide layer had been removed by sand blasting. Here, the continuous signal is not present even on the channel where a gain of 10^4 was used, but deformation would occur to a degree similar to that in the other tests. This leads to the conclusion that the deformation signal, per se, in carbon steel is extremely low level.

Part 1

PT1 - PZT-5 Sensor, Surface Mount, 150 kHz Hi-Pass Filter, 10^4 Gain, 0.2 V/cm
 PT3 - PZT-5 Sensor, Surface Mount, 10 kHz Hi-Pass Filter, 3.3×10^3 Gain, 0.5 V/cm
 PT4 - PZT-5 Sensor, Recessed 3/32 in., 10 kHz Hi-Pass Filter, 3.3×10^3 Gain, 0.5 V/cm

Part 2

PT1, 3, and 4 - Parameters Same as Part 1. Except Vertical Sensitivity is 0.2 V/cm - All Channels

FIGURE 4.1. Panorama - Data from Burst Test Number 8 A-106 Carbon Steel Pipe - 3 in. Diam X 1/4 in. Wall Annealed - As-Received - Hardness R_B75 5 sec/cm Sweep Rate

PT1 - PZT-5 Sensor, Surface Mount, 150 kHz Hi-Pass Filter, 10^4 Gain, 0.5 V/cm
 PT3 - PZT-5 Sensor, Recessed 3/32 in., 10 kHz Hi-Pass Filter, 3.3×10^3 Gain, 0.5 V/cm
 PT4 - PZT-5 Sensor, Surface Mount, 10 kHz Hi-Pass Filter, 3.3×10^3 Gain, 0.5 V/cm

FIGURE 4.2. Panorama - Data From Burst Test Number 9 A-106 Carbon Steel Pipe - 3 in. Diam X 1/4 in. Wall Annealed - Sand Blasted - Hardness $R_B 75$ 5 sec/cm Sweep Rate

However, with the attendant breaking of the brittle oxide surface layer, easily detectable secondary signals are produced. This conclusion is further supported by the micrographs in Figure 4.4 showing the surface condition of the pipe in "as-received" condition and after sand blasting. The oxide layer near the machined flaw of the "as-received" specimen where maximum deformation would occur can be seen to be cracked extensively. This further supports the earlier conclusion that the burst or transient signals are the more reliable indicators in a piping integrity monitor system, since an abundance of these signals was evident in all tests. A note of caution in interpreting the panoramas of test data (Figures 4.1, 4.2, and 4.3) is appropriate. Due to the photographic limitations, only the more prominent transient signals can be recorded without overexposing the film; there is more transient activity than is indicated in these pictures.

Figures 4.1, 4.2, and 4.3 also illustrate the results of the first effort to distinguish between signal transmission by shear wave and by surface wave. As noted, one transducer in each test was recessed 3/32 in. below the surface of the pipe. This should severely attenuate surface wave transmission to that transducer. The difference between it and its surface mounted companion transducers in signal detection is readily evident. The continuous signal in Figure 4.1 appears to be transmitted exclusively by surface wave. In all three tests, some of the burst or transient signals appear to be surface waves, but most of

them apparently are shear waves since they are detected by all transducers. Mode of signal transmission is quite important to the end application because of the different signal attenuation effects involved. Further definition of this parameter is essential.

Although a comprehensive spectral analysis has not yet been performed on the latest burst test data, examination of the transient signals with an oscilloscope shows the basic frequency to be about 25 kHz from the annealed specimens (Figures 4.1 and 4.2) and about 70 kHz from the heat treated specimen (Figure 4.3). Bursts from both types of specimens, however, contained a high frequency component at about 225 to 250 kHz. Figure 4.5 shows this high frequency element with the lower components removed by filtering. In addition to the high frequency aspect, these are of interest because of the sharpness of signal front definition, which will be important to time delay determination for triangulation purposes. It is uncertain at this point whether these high frequency signals are a specimen resonance excited by a very short period transient or a characteristic acoustic emission element. Figure 4.5 shows the comparative response of an accelerometer and a PZT-5 transducer to the transient or burst signals produced by the heat treated specimen. This demonstrates the necessity for a high frequency sensor for comprehensive detection of acoustic emission.

In the course of investigating digital analysis techniques for improving

FIGURE 4.3. Panorama - Data from Burst Test Number 10 A-106 Carbon Steel Pipe - 3 in. Diam x 1/4 in. Wall Sand Blasted - Heat Treated - Hardness $R_B 95$ 5 sec/cm Sweep Rate

A: "As-Received", 180 ° from Machined Flaw.

B: "As-Received", near Machined Flaw.

C: Sand Blasted, near Machined Flaw

D: Same as "A" After Etching

E: Same as "B" After Etching

F: Same as "C" After Etching

FIGURE 4.4. Micrographs (250X) Showing Surface Condition of "As-Received" and of Sand Blasted Burst Specimens After Testing. A 106-B Carbon Steel Pipe - 3 in. diam x 1/4 in. Wall

In Each Photo, Upper Trace Shows Accelerometer Response and Lower Trace Shows PZT-5 Sensor Response. The Same Data Point is Shown in all Cases.

A. Comparative Response of PZT-5 Sensor and an Accelerometer to High Frequency Transients

Two PZT-5 Sensors Showing Signal Frequency and Definition of Time Delay

B. Two PZT-5 Sensors Showing Signal Frequency and Definition of Time Delay

FIGURE 4.5. Acoustic Emission Signals From 3 in. Diam x 1/4 in. Wall Carbon Steel Burst Specimen. Burst Test Number 10, Part 2, 5500 psi Pressure, 0.5 V/cm Vertical, 10 μ sec/cm Horizontal

spectral definition of acoustic emission transient data, the opportunity arose to process sample data through a digital analyzer at the Naval Ordnance Laboratory, Corona, California. Transient data from several burst tests were processed with this system, which operates in real time and is capable of providing continuous spectral analysis in the frequency range of 10 kHz to 90 kHz. If the data tape playback speed was reduced, the analyzer frequency range was extended to 20 kHz to 180 kHz, but equipment limitations precluded any further extension of the range. Figure 4.6 shows samples of the spectral content derived from analysis of acoustic emission transients. The spectrum agrees quite closely with that previously produced

by an analog analyzer using selected data. Data examined with the analog system was selected on the basis of its unusually high signal density, while that examined with the digital system was normal data where the transient signal density was too low for use with an analog system. The significance of this information is the fact that it demonstrates the capability of the digital analyzer to determine the spectral content of a single acoustic emission burst, which is important to this program in determining what signal frequencies predominate with a given set of circumstances.

Two types of fatigue test involving A-212-B carbon steel and a zirconium-niobium alloy were monitored with the emission rate analyzer to determine

FIGURE 4.6. Digital Analysis: Transient Acoustic Emission Data

general response patterns. The results are shown in Figure 4.7, 4.8, and 4.9. The A-212-B carbon steel was tested in the form of a cantilever beam driven in reverse bending by an electrodynamic shaker table at 40 cycles per second. In spite of the very adverse noise environment generated by this test arrangement, a distinct emission pattern could be detected by using filters. The zirconium-niobium was tested in tube form, and the stress was cycled from zero to a positive value by cycling internal hydraulic pressure. (The test was being run primarily for purposes other than study of acoustic emission.) The cycle rate was 400 cycles per hour. Although two different materials and two different basic test procedures were involved, the similarity of results—the early peak and decline with a subsequent steady increase to failure—is quite encouraging. Obviously, more definitive work is in order.

A prototypic, high temperature, piezoelectric transducer for use in acoustic emission test work is being fabricated. The initial version will use PZT-5 crystals that can withstand only limited service at the required 600 to 650 °F temperature range. However, subsequent use of a high temperature piezoelectric material such as lithium niobate, once the transducer design is proven, would make this a second candidate sensor for use on-reactor. The first model of this transducer has been preliminarily tested for sensitivity, and it compares very favorably with commercial PZT-5 sensors being used for acoustic emission study.

The acoustic emission detection system used in study work has been upgraded to provide linear response to 300 kHz. The magnetic tape recorder is the limiting component; the transducer and amplifiers are linear to 400 kHz. A market survey of low-noise amplifiers showed a commercial amplifier (Ithaco Model 144L) has characteristics well suited to acoustic emission detection. It is low noise (7 μ V referred to input) has a 40 dB gain, a band width to approximately 400 kHz, and is small. This is potentially applicable as part of the prototypic monitor system.

Work Planned for the Next Quarter

Burst testing will be continued by introducing different pipe sizes, wall thickness, and pipe lengths. Study of signal propagation mechanics will also be continued as part of these tests.

Single-edge-notch specimen studies will be initiated to study specific portions of the known acoustic emission spectrum.

Fatigue and stress corrosion cracking will be investigated for acoustic emission characteristics.

Acoustic emission in heavy section steel will be studied in a burst test of a 24 in. diameter by 1-3/4 in. wall pipe section at Battelle-Columbus and by participating in local heavy-section steel tests.

A system analysis or theoretical study of various functional approaches to an acoustic emission monitor system will be initiated.

Development of a high temperature transducer will continue and will include both the electrostatic and the piezoelectric concepts.

4.10

BNWL-537

FIGURE 4.7. Relative Acoustic Emission Rate
 A-212 Carbon Steel Failed by Reverse Bending

FIGURE 4.8. Relative Acoustic Emission Rate
 A-212 Carbon Steel Failed by Reverse Bending

FIGURE 4.9. Acoustic Emission Rate Zr-Nb Tube
 Failed by Internal Pressure Cycling

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ENVIRONMENTAL STUDIES

R. F. Foster

COLUMBIA RIVER SEDIMENTATION STUDIES

J. M. Nielsen

Radionuclide analyses and calculations have been completed for samples of water and suspended sediment from 21 verticals at various points in the Columbia River estuary near Astoria. At least three depths per vertical were analyzed, many where a salt water wedge existed near the river bottom. Results for the water indicated that, in general, radionuclide concentrations were quite uniform with depth except where salt water occurred. In these places, ocean water diluted the radionuclide-bearing river water to give lower concentrations. The nuclide ^{137}Cs was an exception to this, due to the fact that the concentration of ^{137}Cs in ocean water is as high or higher than in river water. In general, suspended sediment samples taken near the bottom contained greater amounts of radionuclides than those taken near the surface. This is as expected, since greater amounts of sediment are carried near the bottom. The results from these samples will aid in the establishment of a semiroutine sampling program on water and suspended sediment at Vancouver, Beaver Army Terminal, and Astoria so that the inventories and depletions of radionuclides in the estuary can be calculated. It is planned to start this program next quarter.

Analysis work was completed on 90 bottom sediment samples from various parts of the Columbia River Estuary. Results indicated that the concentrations of radionuclides vary widely in different environments of the estuary.

Analyses of particle size separates from various locations in the Columbia River indicate that although finer particles retain higher concentrations of radionuclides, the differences are not as great as differences in surface area, and thus the coarse particles retain surprising amounts of activity.

DISPOSAL OF REACTOR OFF-GAS
INTO SOIL SYSTEMS

L. G. King

During this quarter, methods have been finalized for analyzing the injection of gas into homogeneous media through a single well. A description of these methods was included in the January, February, March, 1967, Quarterly Report, and the dimensionless curves for flow rates were described. Similar dimensionless curves have been completed giving the minimum time for gas travel back to ground surface during continuous injection. A draft of a report including these results was begun during this quarter.

The major emphasis this quarter has been on obtaining working programs for modeling the field injection site at

the National Reactor Testing Station (NRTS) Idaho. Since the plan is to inject gas into the fractured basalt above the water table, the flow may take place through the basalt as well as the overlying alluvial material. Such a system can not be modeled adequately with a homogeneous media. Hence, solution in closed form will not be available and the calculations must be performed numerically. The field flow system will be modeled using a layered model with one permeability value for the basalt and a different value for the alluvium.

For a numerical model to the above system, much economy can be gained in solution time on computers without sacrificing accuracy if a variable grid spacing is used. In such an approach, a fine mesh is used close to the injection well where gradients are steepest, and spacing is made larger as distance from the well increases. Work has been underway toward finding acceptable grid geometries for this model. The computer program has been altered to accommodate the variable grid spacing, and work is progressing on obtaining the best node configurations.

Results of planned air-injection tests in the field at NRTS are needed to arrive at permeability values for this model. These Tests should be completed during the coming quarter.

SIMULATION MODELING OF THERMAL GENERATION IN SELECTED RIVER SYSTEMS

R. T. Jaske

Computations for the upper portion of the Illinois River below Dresden are being carried out for the purpose of

testing the Pacific Northwest Laboratory simulation model and making preliminary estimates of the effects of operation of Dresden II and III plants. These computations have now been completed down to Mile 230. They indicate (Figure 5.1) that significant alteration of the annual mean temperature of the Illinois River can be expected if the present river discharge rate is maintained after the reactors go into operation. This effect is more pronounced in the winter than in the summer, since increased evaporation at high summer temperatures tends to offset the heat addition more than during the winter months. A report summarizing the computation to Mile 230 is now being prepared.

Additional work to extend the original scope of the study down to Illinois River Mile 80 has been started. This extension appears desirable in order to determine how far downstream the measurable effects of the proposed plant can be expected to persist. All information is available for this extension.

Two thermographs were installed on the Illinois River during June: one at Dresden Island Dam and the other at Starved Rock Dam, (Ottawa). Records are now coming in, and computer cards are being punched in order to test the computational system with current data.

All information for the Deerfield River case is now available and is being processed for computer operation. A field trip was made in June in order to obtain river profile information not available from maps and records of the New England Power Company.

FIGURE 5.1. Equilibration Distance for Varying Degrees of Power Development at the Dresden Site

Geophysical Exploration of Rattlesnake No. 1 Well

J. R. Raymond, and D. D. Tillson

Field investigations of the geophysical and hydrologic characteristics of the Standard Oil Co. No. 1 Rattlesnake Hills Well were initiated on May 30, 1967 and completed on June 10, 1967. The well was plugged to pretest conditions, and the site was abandoned.

The process of reopening the well and reconditioning the drilling fluid did not pose any unusual problems that might

normally be associated with a 10-year old well. A number of bridges that had formed in the interflow zones due to dewatering were easily drilled out. The original drilling fluid was encountered at a depth of approximately 3100 ft from the surface. Cleanout was successful for 9157 ft of the original 10,655 ft drilled. The condition of the well was a good indication of the high degree of stability of the basalt flows and associated interbeds.

Ten different wire-line logging tools were utilized to investigate the

well. All work was done by Schlumberger Well Surveying Corporation, Houston, Texas. A brief description of each logging operation and the preliminary results are as follows:

- Dual Induction Lateralog was used to measure formation conductivity and resistivity. Calculations based on these data help to identify the nature of the pore fluid, presence of gas, qualitative permeability, and lithologic delineation. The basalt flows exhibited an average resistivity of 2000 ohms-m²/m for the first 4000 ft, 100 ohms-m²/m from 4000 to 7000 ft, and 1000 ohms-m²/m from 7000 to 9000 ft. The resistivity of the interstitial water follows the same pattern except for the first 1400 ft, which appears to be affected by surface water.
- Microlateralog is a focusing system that provides a very accurate determination of formation resistivity close to the wall of the hole where flushing has taken place by drilling fluid. Accordingly, the porosity and qualitative nature of the permeability can be determined. The data collected are of little use in the basalt flows because of the high resistance found. Practically all of the interflow zones, however, showed good resolution of data.
- Sidewall Neutron Porosity is a directionally sensitive epithermal neutron detection system that utilizes a Pu Be neutron source. The primary use of this tool is to measure porosity and lithology variations. The data collected indicate an apparent porosity average of 5 to 10% for all the basalt flows and apparent porosities as high as 60% for some interflow zones.
- Sonic Logging fundamentally involves the recording of the time required for a sound wave to travel through a definite length of formation. Since the speed of sound in subsurface rocks depends upon the elastic properties of the matrix and fluid content and porosity of formations, this tool is useful for detailed lithologic studies. A velocity of 21,300 ft/sec for the basalt flows was determined from the initial examination of data. This figure is compatible with laboratory measurements previously reported for basalt.
- Sonic Amplitude is a measurement of the attenuation of seismic waves by changes in the elastic properties of the matrix. When other data suggest a constant matrix, any change in the amplitude will be the result of physical changes such as fractures at faults. The data from this log have not yet been evaluated completely.
- Microseismogram is an extension of the sonic amplitude device in that sound waves are recorded. However, this tool can resolve and record the separate components (shear, compression and Rayleigh waves) and display them in variable density form. The main use of this tool is to delineate vertical from horizontal fractures. Evaluation of these data is in progress.
- Formation Density uses a radiation tool that measures the absorption of gamma rays from a ¹³⁷Cs source and determines the bulk density of the formations. This information, coupled with the sonic or sidewall

neutron porosity results, can be used as a lithologic tool and as a check against porosity measurements. The data recorded from this log show that the average density of the basalt is 2.95 g/cm^3 . This figure is compatible with previous laboratory measurements.

- Spontaneous Potential is a record of naturally occurring potential differences between a surface electrode and an electrode in the mud column as it moves past different formations. Because the basalts exhibit such a high resistance, the potential differences were not satisfactorily recorded. Some anomalous indications in the basalt flows from 7000 to 9000 ft were observed, but these indications may indicate zones of high permeability.
- Sidewall Cores were taken from 60 separate levels. Twenty-nine, well formed cores and 22 samples of mud or partial recovery were obtained. Nine sample attempts were unsuccessful and no recovery was achieved. All of the cores that exhibited a high degree of recovery came from the interflow zones. Initial examination of the samples indicates that these interflow zones are mostly weathered and altered basalt rather than volcanic tuff as had been assumed previously. Detailed petrographic examination of thin sections and some selected X-ray analysis remain to be done.

Statistical analysis of spectrochemical data taken at 100-ft intervals during the original drilling is now in progress. Initial indications show that gross chemical variations exist

between the 0 to 4000 ft, 4000 to 7000 ft, and 7000 to 9000 ft levels.

Thin sections from a drill core taken at 8080 to 8100 ft were re-examined in more detail. It is now believed that this core is from a basic augite andesite formation similar to formations found on the surface 75 miles west of the well and not typical Columbia River basalt.

Seven drill stem tests were made at various levels. The objectives of the tests were: (1) determination of the formation fluid hydrostatic pressures, (2) measurement of formation permeability, and (3) sampling of formation fluid. The tests involved isolating a 76-ft section of the well and making pressure and fluid flow measurements at seven selected intervals. Both basalt interflow zones and fractured portions of the basalt flows were tested. The results of the tests showed permeabilities that range from 19.5 to 0.1 millidarcies. These values are 1/100 to 1/1000 of the permeabilities of the Ringold formation that underlies the Hanford Project. The potentiometric surface in feet below ground surface (the depth to water if the given zone were isolated and opened to atmosphere) range from 926 to 7571 ft. There is good evidence that if vertical flow occurs, the direction would be from upper aquifer to lower aquifer. The evidence also indicates that there is not a high degree of communication between the different zones. Fluid injected (under proper pressure control) into a formation at depth would move downward if vertical movement occurred, and near-surface aquifers would not be

contaminated. Fluid samples were obtained on four tests, and all showed varying degrees of contamination. Chemical analysis of the fluid samples is in progress; initial observations indicate that the formation fluid is low-salt content water (chloride con-

tent less than 50 grains/gal). No evidence of saline or brackish water was found. Two drill-stem tests encountered natural gas and, one fluid sample contained dissolved gas. This gas is probably methane and not petroleum gas.

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