NRC Research and/or Technical Assistance Rept

PDR

INTERIM REPORT

Accession No. _____

Contract Program or Project Title: ACOUSTIC EMISSION/FLAW RELATIONSHIPS FOR INSERVICE MONITORING OF NUCLEAR PRESSURE VESSELS

Subject of this Document: MONTHLY PROGRESS - OCTOBER, 1982

Type of Document: INFORMAL LETTER REPORT

Author(s): PH HUTTON, RJ KURTZ

Date of Document: NOVEMBER 17, 1982

Responsible NRC Individual and NRC Office or Division:
Dr. Joe Muscara
Materials Engineering Branch
Engineering Technology Division



BATTELLE
Pacific Northwest Laboratory
P. O. Box 999
Richland, WA 99352

Prepared for
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

INTERIM REPORT

Battelle
Pacific Northwest Laboratories
P.O. Box 999
Richland, Washington U.S.A. 99352
Telephone (509) 375-2157
Telex 15-2874

November 17, 1982

Dr. Joe Muscara
Materials Engineering Branch
Engineering Technology Division
Nuclear Regulatory Commission
Mail Stop 5650NL
Washington, D.C. 20555

Dear Joe:

MONTHLY LETTER REPORT - OCTOBER, 1982
ACOUSTIC EMISSION CHARACTERIZATION OF
FLAW GROWTH IN A533B PRESSURE VESSEL STEEL
FIN. NO. B2088

## ACCOMPLISHMENTS

- Started ZB-1 vessel test.
- Continued efforts to install AE signal leads at Watts Bar Unit 1 reactor.
- Continued stress corrosion cracking tests for pipe material characterization.
- Started engineering prototype AE system.
- Presented a paper at the London Conference on Periodic Inspection of Pressurized Components.

## VESSEL TEST

The primary emphasis in October focused on the ZB-1 vessel test at Mannheim, West Germany. The chronology of activities on the ZB-1 test through most of October has been compiled in a trip report. To avoid repetition, a copy of that trip report is appended.

Battelle

Figure 1 shows the location of the test facility along the Rhine River at Mannheim. It is part of the Grosskraftwerk Mannheim (GKM) Utility plant site and is administered by GKM. Instrumentation is located in a trailer (Figure 2) situated just outside the test bunker entrance. Figures 3 and 4 show the arrangement of the AE instrumentation and vessel pressurizing controls inside the trailer.

The ZB-1 test vessel is situated about 50-60 feet underground on the bottom level of the test bunker (Figure 5). Concentrating on the vessel, Figures 6 and 7 show the COD gauges and flow noise simulator installed inside the vessel. The COD gauge on flaw A was subsequently removed because the vessel wall penetration for those leads developed a persistent leak under moderate pressure.

Stainless steel cladding with intentional debonding and underclad cracking has been installed on the inside of the vessel wall half way between the KS07. (Figure 8)

PNL AE sensors and accessory devices are situated on both the A533B insert (Figure 9) and the KS07 insert (Figure 10). A primary waveguide AE sensor array (WG 1, 2, 3, and 4) is mounted on each of the inserts by threading the waveguides into drilled and tapped 5-40 by 3/16 inch deep holes. Lower frequency hydrostatic test monitor sensors are situated on the A533B insert in an array similar to the waveguides (Hydro 1, 2, 3, and 4). These are mounted on the surface using magnets. One other waveguide AE sensor array which does not show in the photos is installed at each end of the cylindrical portion of the vessel. This array includes the total vessel cylinder. The waveguides are pressure coupled to the vessel surface to simulate mounting on a reactor vessel.

As described in the attached trip report, the KS07 degraded material insert showed indications (AE plus audible "pop-ins") of impending failure before reaching full operating pressure of 240 bar on the Step 1 hydrostatic test. As a result of this, the test has been stopped to replace the KS07 insert. The Germans expect this to be completed by the end of December which would allow resumption of testing in early January 1983. PNL staff members have returned to PNL for the duration of the delay.

Data from the Step 1 hydrostatic test is being analyzed and compiled for reporting. It appears at this point that AE signal amplitude could become a valuable parameter in analyzing AE data.

Battelle

## REACTOR MONITORING

Work is continuing on installation of permanent AE signal leads at TVA Watts Bar Unit 1 reactor. The work is progressing very slowly but construction management assures us that the work will be completed before hot functional testing of the reactor system.

## PIPE MATERIAL CHARACTERIZATION

The accelerated stress corrosion cracking (SCC) specimen failed at an installation weld apparently due partially to stress corrosion cracking. The test weld in the specimen is being examined to define the extent of SCC for correlation with detected AE.

The long term SCC test specimen continued under test with no AE indications yet.

## ENGINEERING PROTOTYPE AE SYSTEM

Design of the engineering prototype AE monitor system is in progress. The basic design incorporates 48 AE sensing channels with capability to expand the number of channels. The ultimate number of data channels in one system will be determined not only by technical limitations in data processing speed, but also by the question of how much monitoring capability should be dependent on one processor unit. We are planning to fabricate only 24 sensor channels at this time since this will be sufficient for Watts Bar Unit 1 reactor monitoring.

Consideration of leak detection monitoring is also being addressed. Preliminary telephone discussions have been held with Dave Kupperman, Argonne Laboratories and Dave Prine, GARD (NRC Leak Detection Program) on this topic. Generally, they are considering using the same sensors as the AE system and branching in the analog stage of the signal conditioner to feed data to a leak detection analyzer. A meeting is needed, however, to reach the level of detail needed to confirm that this is the best path. Such a meeting is tentatively planned for early December.

## GENERAL

A paper describing current accomplishments and planned work on this program was presented at the Conference on Periodic Inspection of Pressurized Components in London, England on 10/12/82.

Battelle

## SCHEDULE AND FUNDING

The cost summary in Table 1 is recycled to show FY83 costs. The carryover FY82 funds will definitely sustain the program to the first of December. ZB-1 vessel test costs for October are quite high; however, they include equipment shipping costs and the cost of extra personnel at the test site for system installation which are nonrecurring costs. Subsequent monthly costs for operating the test should be substantially less than the October figure.

Program schedule is given in Figures 11 and 12. We expect to revise this schedule by next month to drop completed work and show more detail of current and future activities.

## PLANS FOR OCTOBER

- Analyze and compile data from ZB-1 test.
- Continue efforts to complete installation of cabling at Watts Bar.
- Perform a high temperature fatigue test on A106B pipe material.
- Continue stress corrosion cracking testing of stainless steel piping.
- Continue work on engineering prototype AE monitor system.
- Prepare annual report of FY82 program accomplishments.

Yours very truly,

P. H. HUTTON
Project Manager

PHH:kw

Attachments

Table 1

AE/FLAW CHARACTERIZATION PROGRAM

SUMMARY OF FY83 COSTS

| | | | |
|---|---|---|---|
| Total Funding: | Expense - FY83 (Fin. No. B2088) | | $ --- |
| | - FY82 carryover (Fin. No. B2088) | | 235.0K |
| | | Total | $235.0K |
| | Capital - FY83 | | $ --- |
| | - FY82 carryover | | 141.0K |
| | | Total | $141.0K |
| Cost to 11/1/82: | Expense - Spent | | $ 61.3K |
| | - Balance | | 173.7K |
| | Capital - Spent | | $ 7.6K |
| | - Balance | | 133.4K |

Major FY83 Cost Elements to Date

EXPENSE

| | | |
|---|---|---|
| ZB-1 Vessel Test and Analysis | | $ 46.5K |
| Reactor Testing | | |
| - TVA Costs | | 1.5K |
| - Preservice Reactor Test Monitoring | | --- |
| Piping Material Characterization | | |
| - Stress Corrosion Cracking Tests | | 2.5K |
| - Fatigue Crack Growth Tests | | --- |
| Code Case Preparation | | --- |
| AE Monitor System & Pattern Recognition | | 3.0K |
| Irradiated Fracture Tests | | --- |
| Program Management, Reporting, Miscellaneous | | 7.8K |
| | Total | $ 61.3K |

CAPITAL

| | | |
|---|---|---|
| Engineering Prototype AE System | | $ 7.6K |
| | Total | $ 7.6K |

Table 1

(Cont'd)

Projected Application of Remaining FY82 Funds

EXPENSE

| | | |
|---|---|---|
| ZB-1 Vessel Test and Analysis | | $ 20.0K |
| Reactor Testing | | |
| - TVA Costs | | 115.0K |
| - Preservice Reactor Test Monitoring | | --- |
| Piping Material Characterization | | |
| - Stress Corrosion Cracking Tests | | 10.0K |
| - Fatigue Crack Growth Tests | | 12.0K |
| Code Case Preparation | | --- |
| AE Monitor System & Pattern Recognition | | 10.0K |
| Irradiated Fracture Tests | | --- |
| Program Management, Reporting, Miscellaneous | | 6.7K |
| | Total | $173.7K |

CAPITAL

| | | |
|---|---|---|
| Engineering Prototype AE System | | $123.4K |
| Support Components for ZB-1 Vessel Test | | 10.0K |
| | Total | $133.4K |

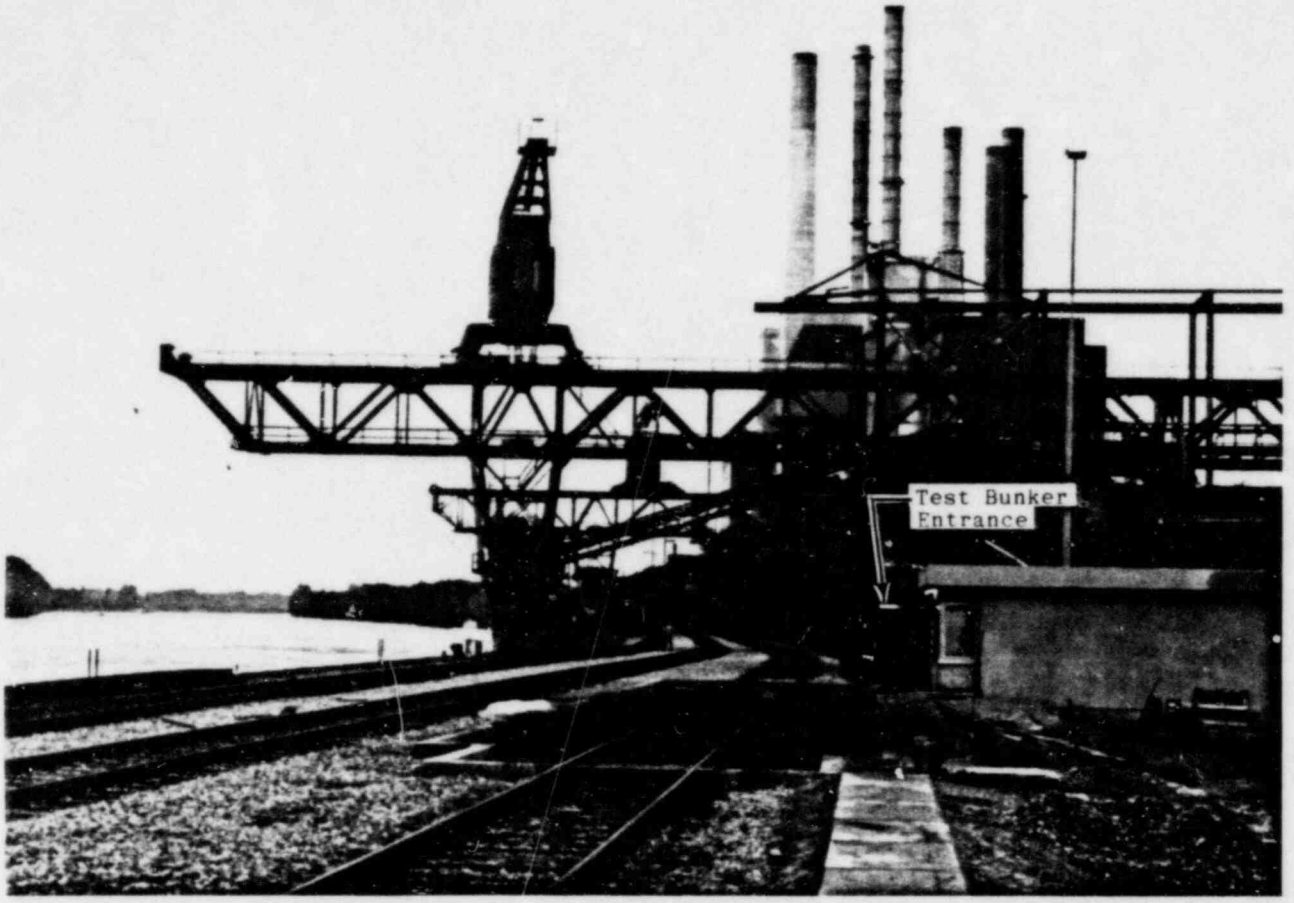


Figure 1. ZB-1 Vessel Test Site

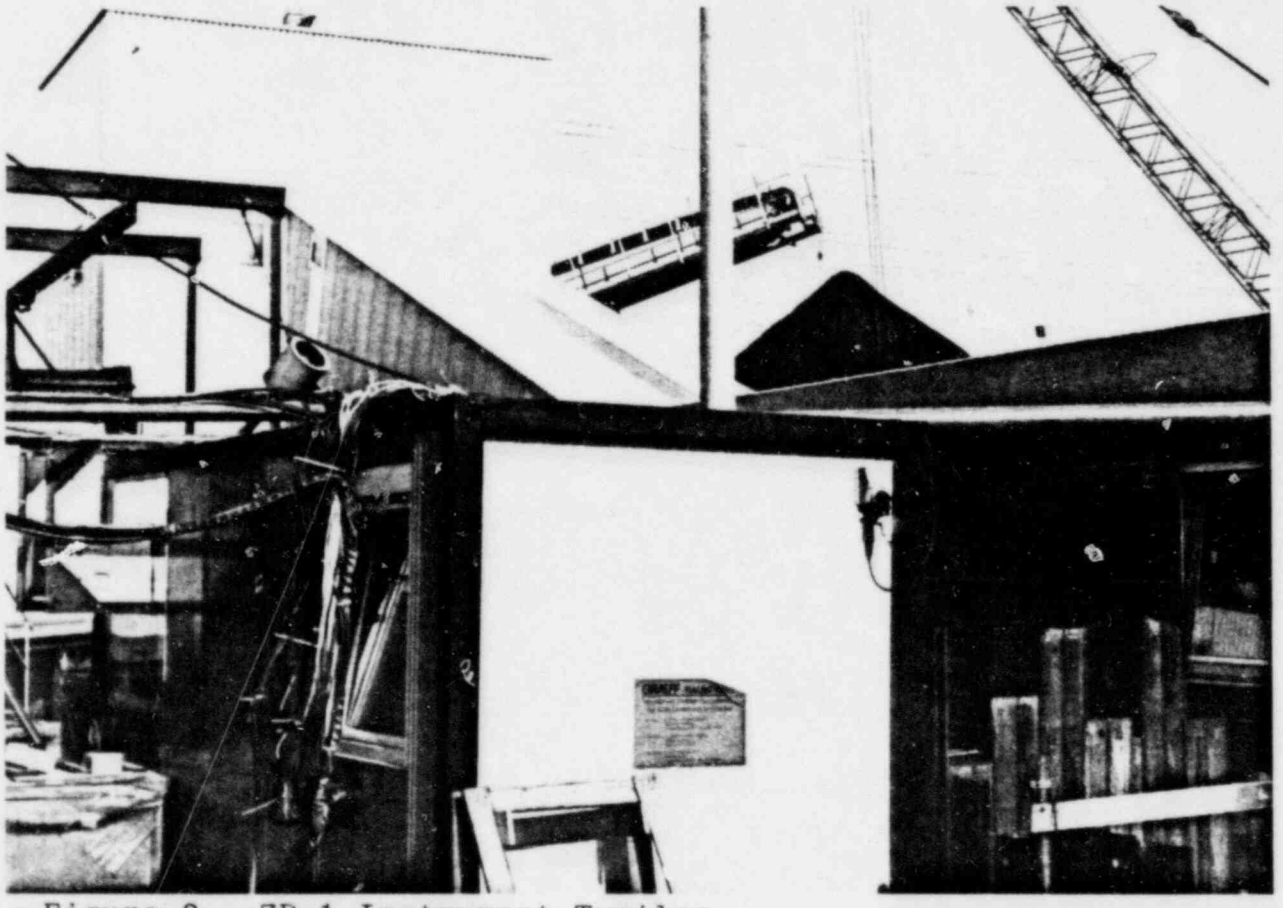

Figure 2. ZB-1 Instrument Trailer

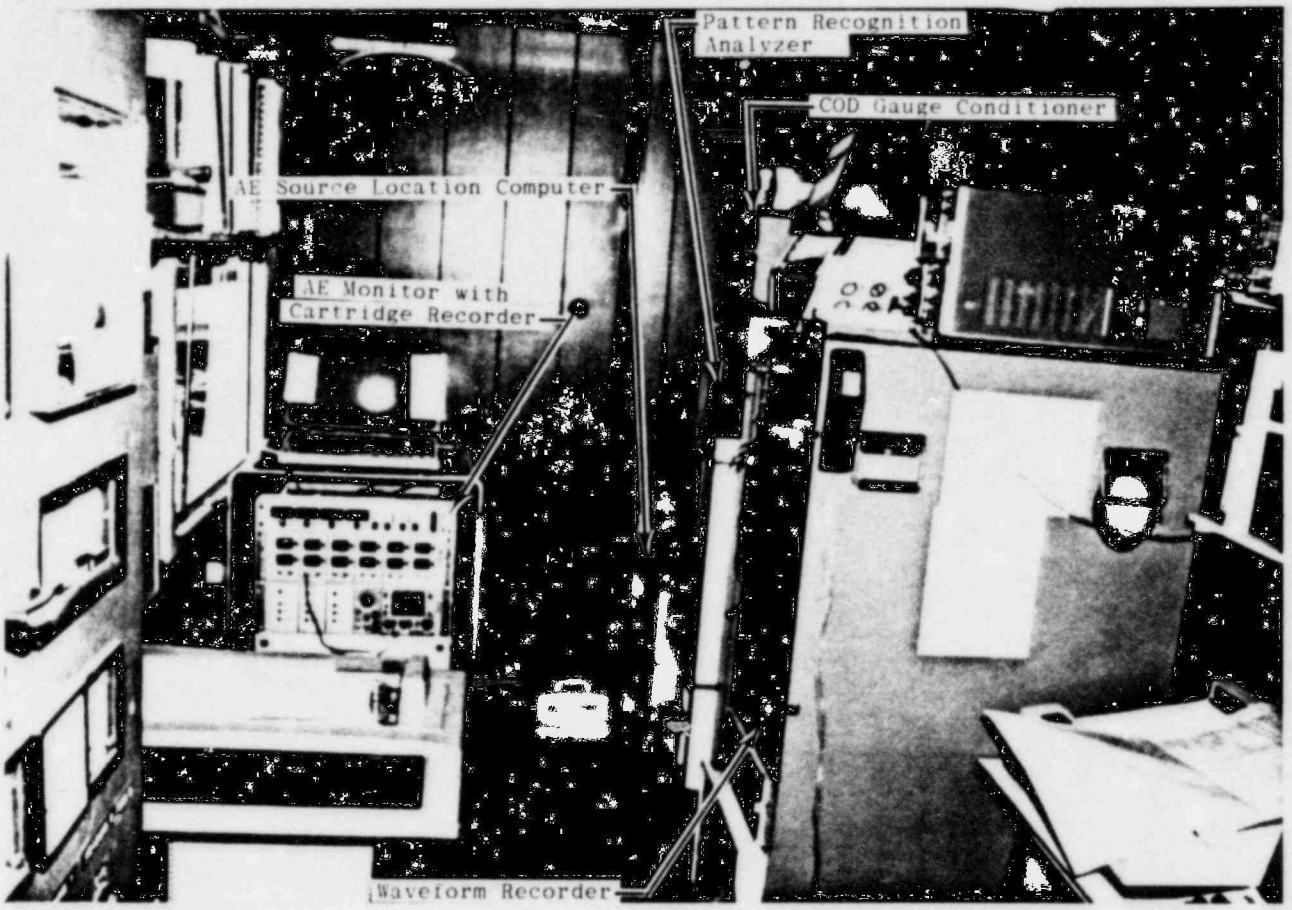


Figure 3. AE Instrument System - ZB-1 Test

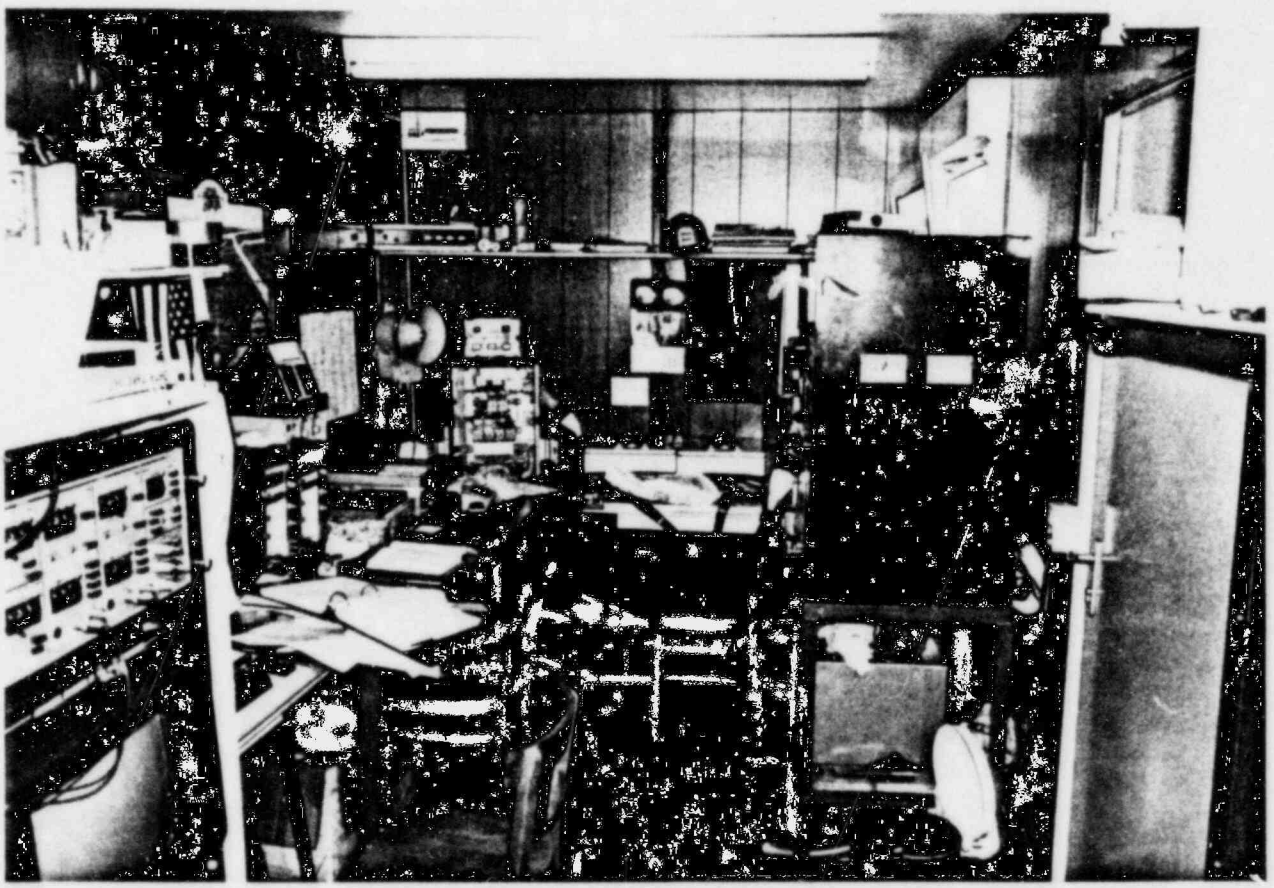

Figure 4. Pressurizing Control Instruments - ZB-1 Test

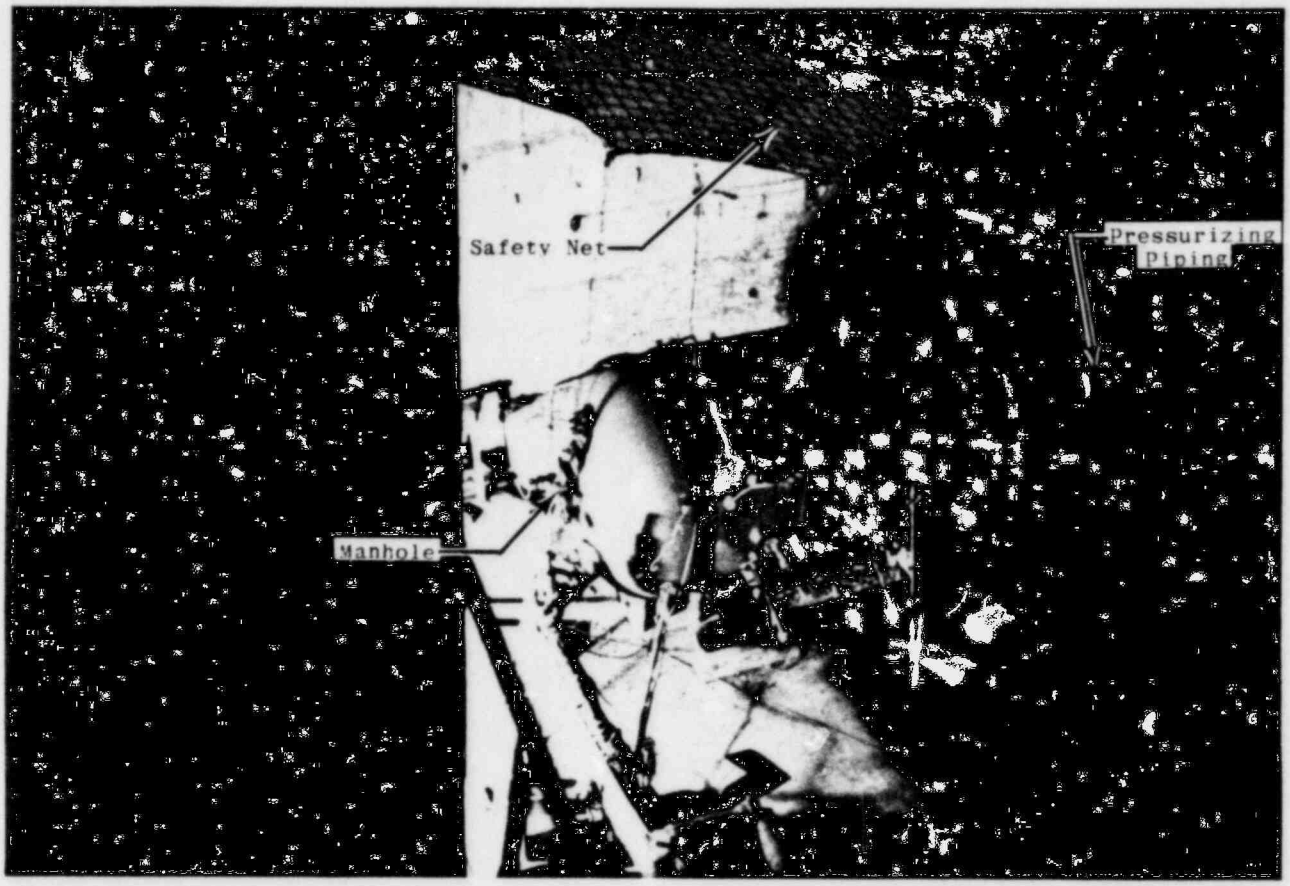


Figure 5. ZB-1 Vessel in the Test Bunker

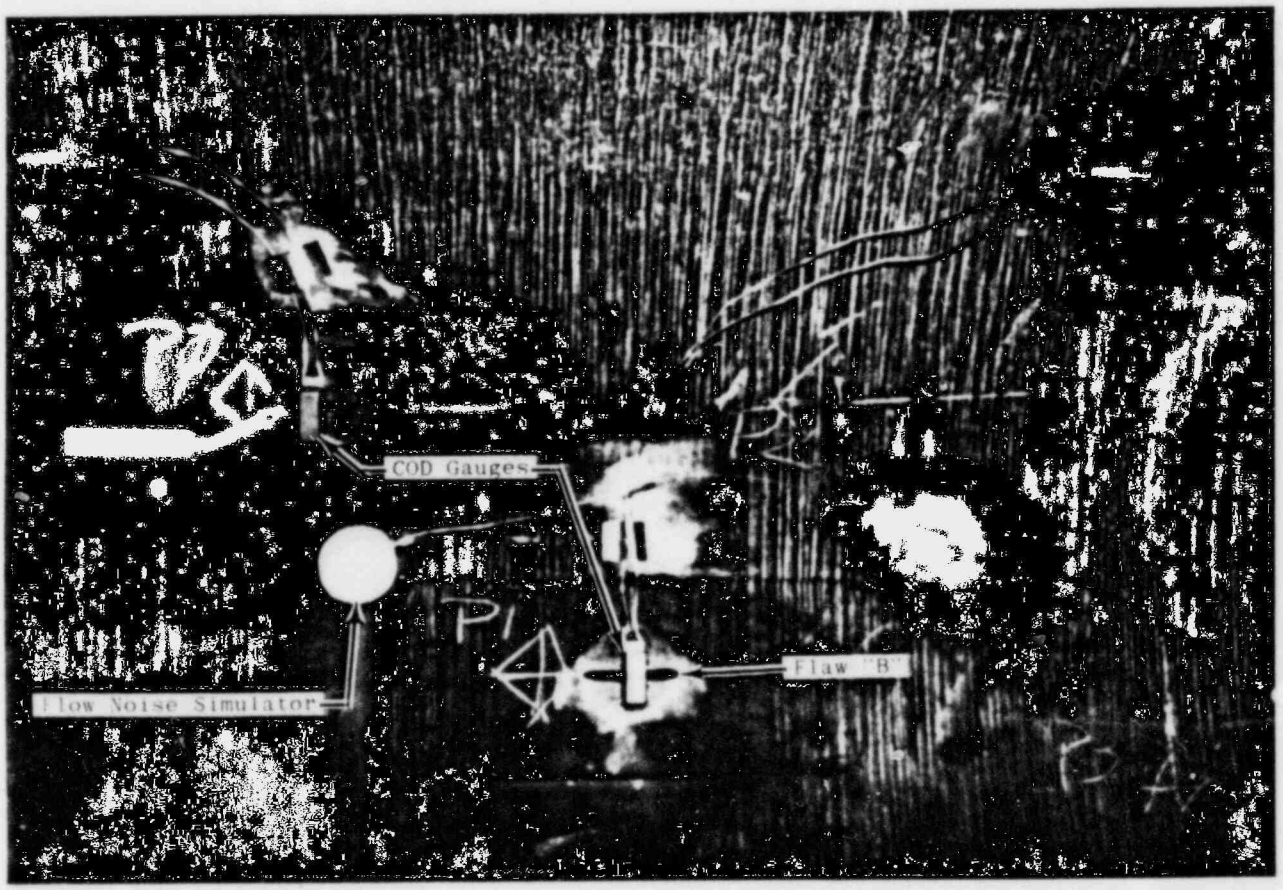


Figure 6. Inside Surface - A533B Implant - ZB-1 Vessel

Figure 7. Instrumentation Arrangement on I.D. of A533B Implant - ZB-1 Vessel

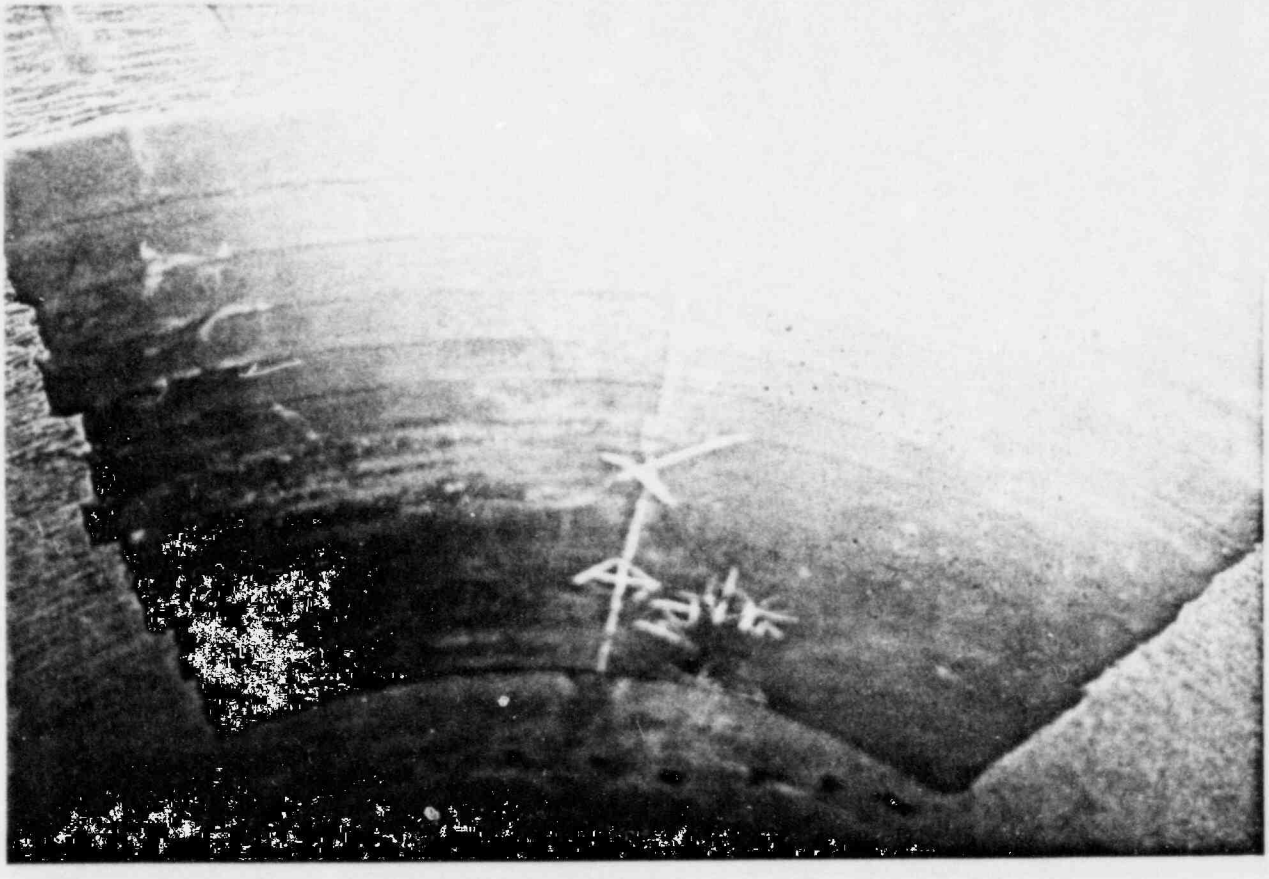

Figure 8. Clad Section with Unbond and Underclad Cracking - ZB-1 Vessel

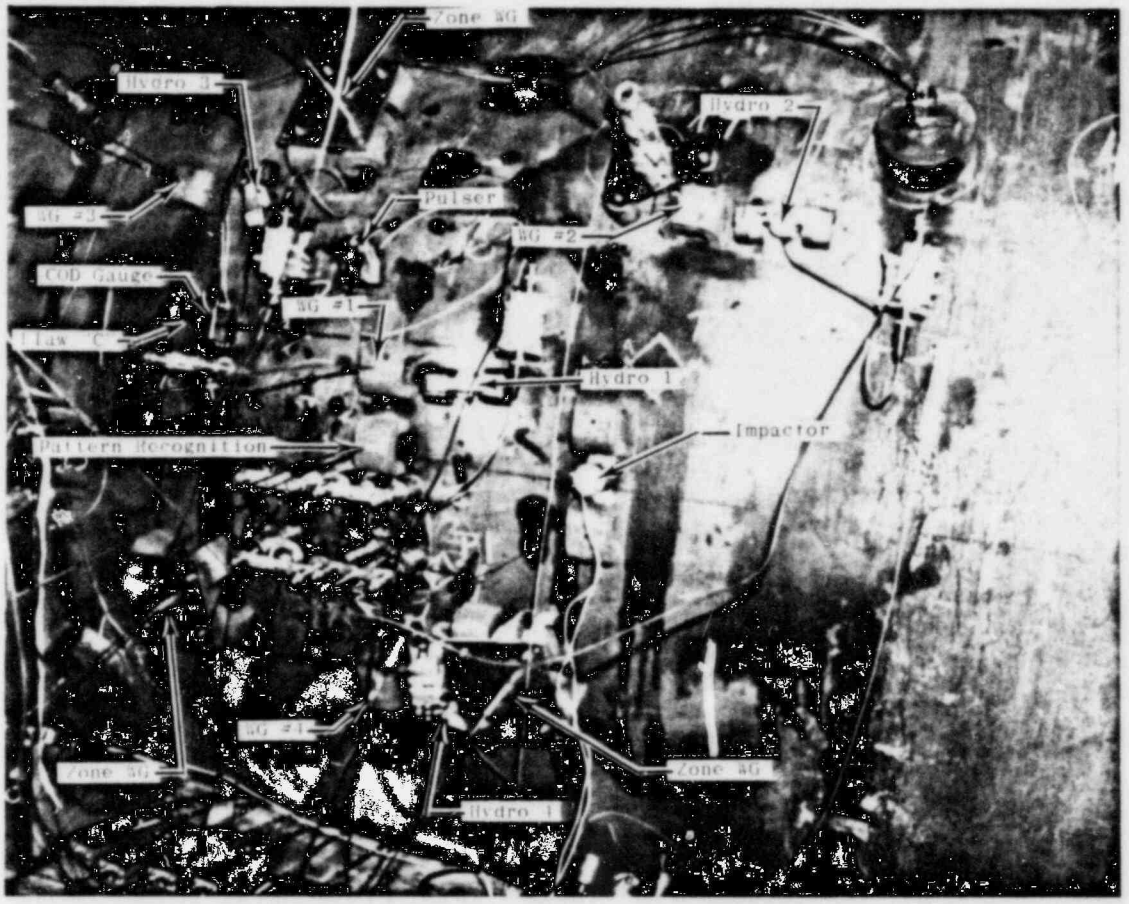


Figure 9. Sensors on A533B Implant - ZB-1 Vessel

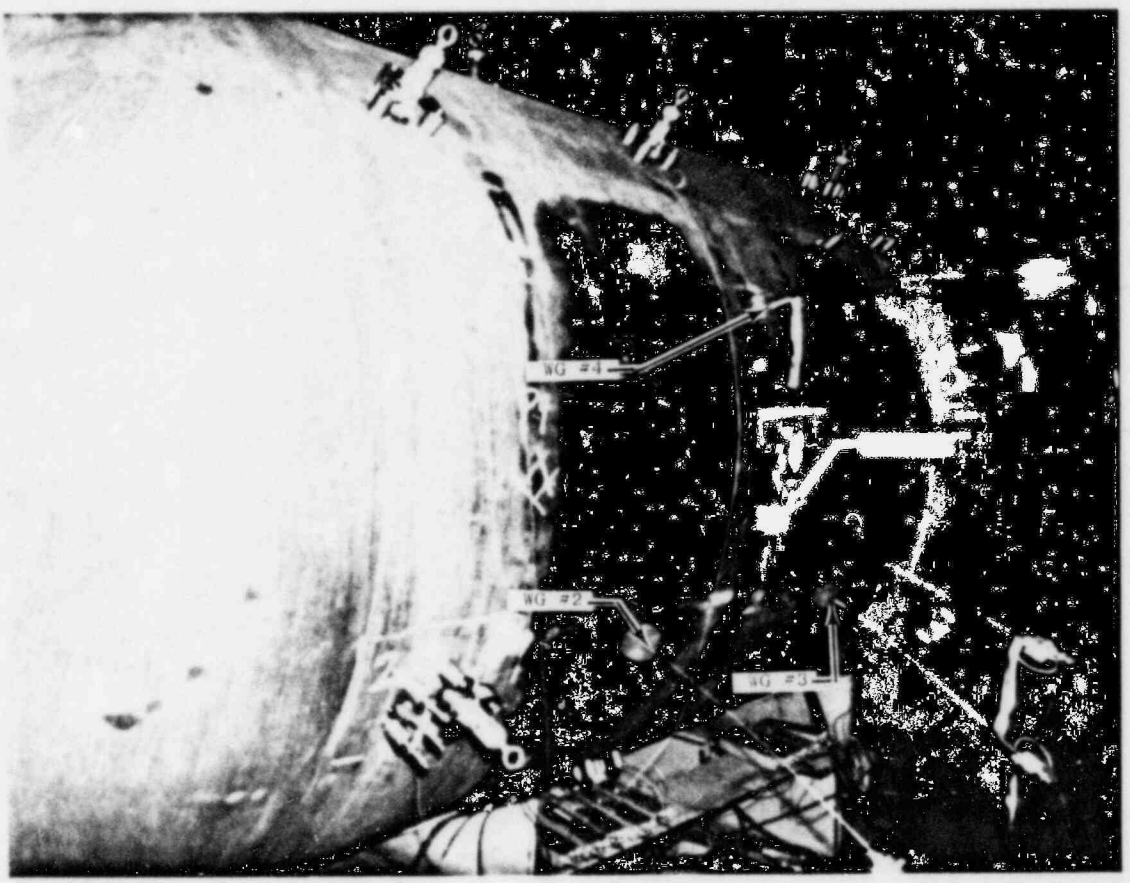


Figure 10. Sensors on KS07 Implant - ZB-1 Vessel

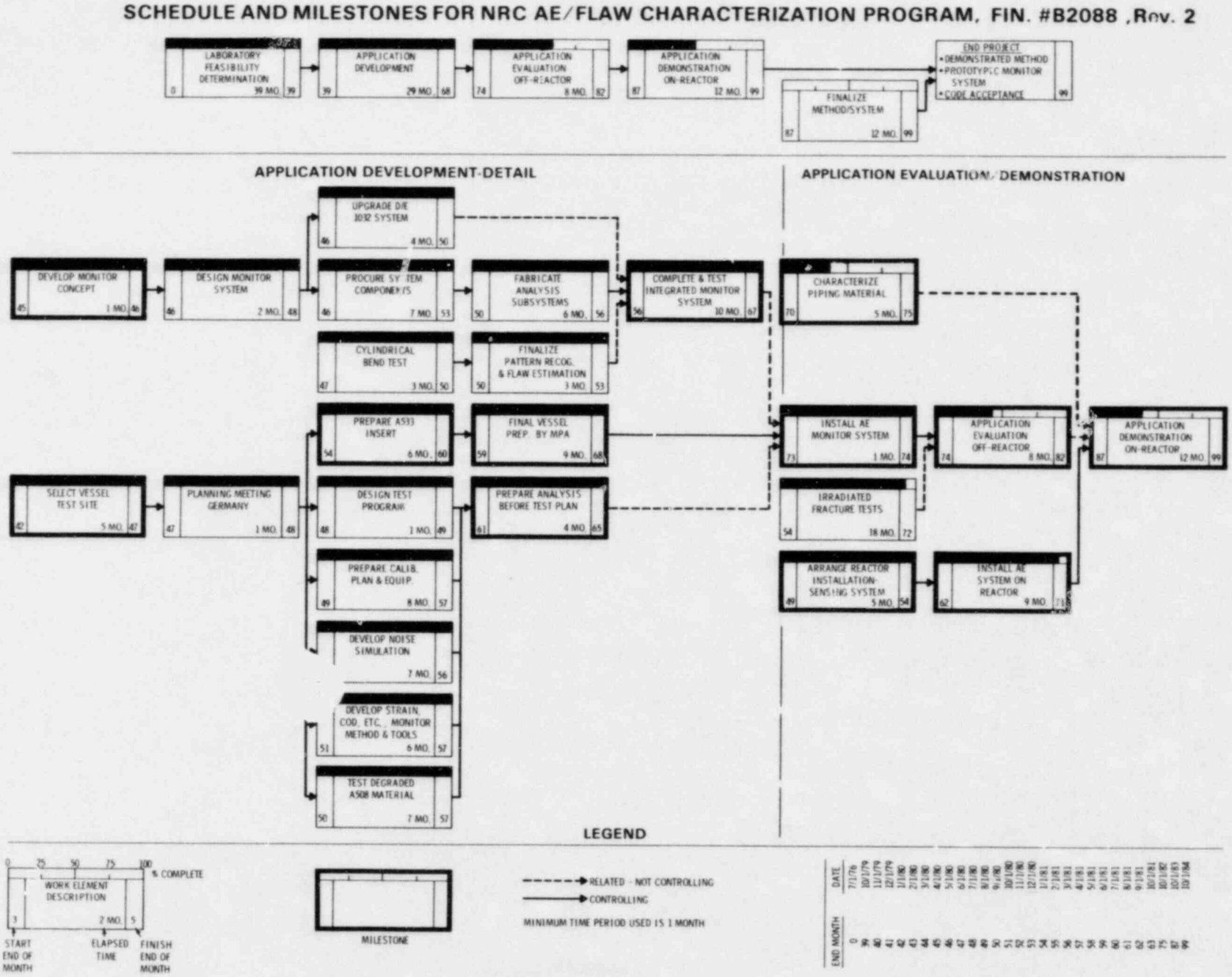


Figure 11. Program Schedule and Milestones.

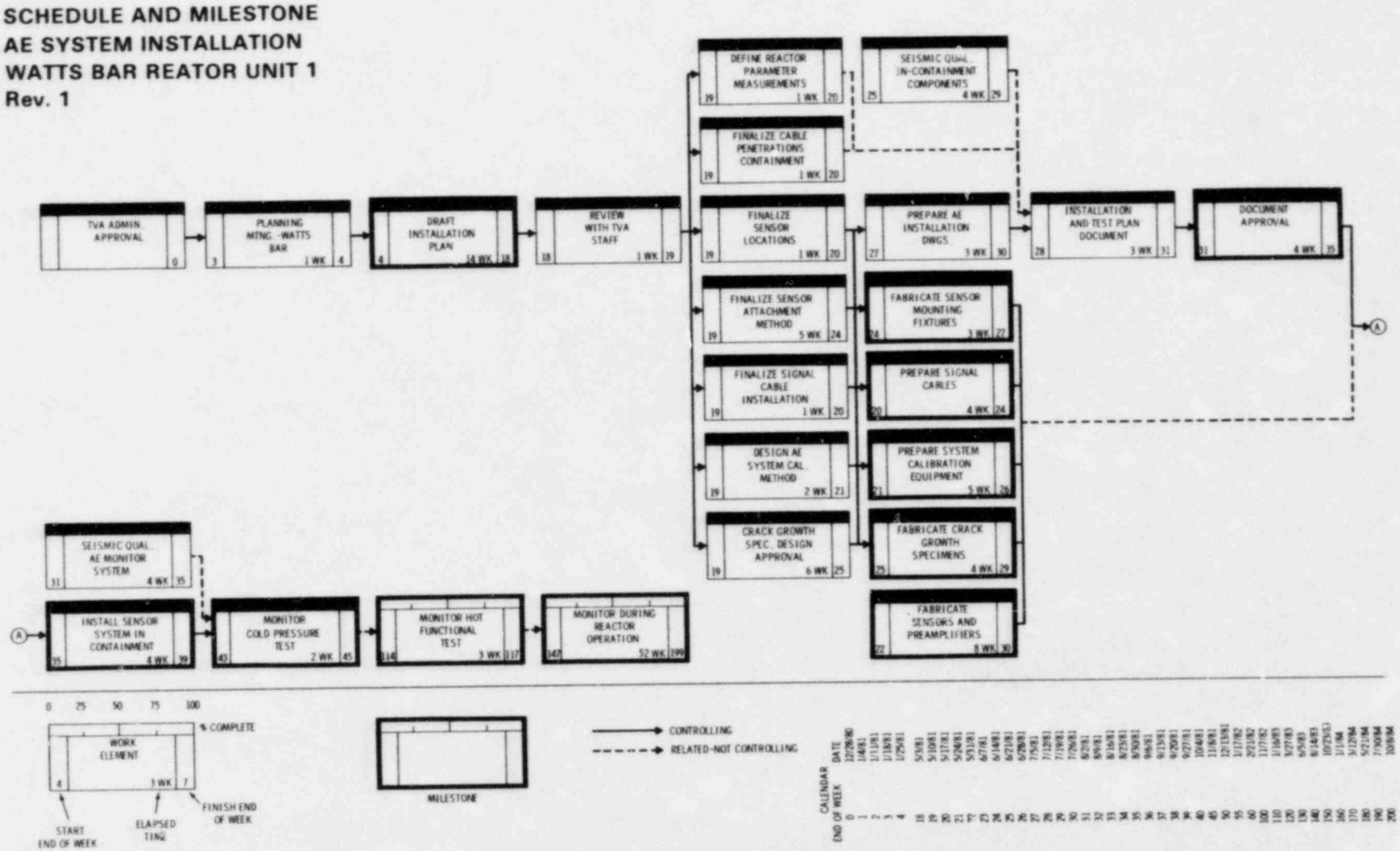


Figure 12. Reactor Testing - Schedule and Milestones

Battelle
Pacific Northwest Laboratories
P.O. Box 999
Richland, Washington U.S.A. 99352
Telephone (509) 375-2157
Telex 15-2874

October 28, 1982

bcc: JF Dawson
PG Doctor
PH Hutton
RJ Kurtz
RB Melton
RA Pappas
GJ Posakony
CB Perry
JR Skorpik
AM Sutey
PHH/lb

Dr. Joe Muscara
Materials Engineering Branch
Engineering Technology Division
Nuclear Regulatory Commission
Mail Stop 5650NL
Washington, DC 20555

Subject: Trip Report for October 1-23, 1982

Dear Joe:

The subject trip was devoted to two purposes - participate in start of the ZB-1 vessel test at Mannheim and Stuttgart, West Germany, and participate in the Conference on Periodic Inspection of Pressurized Components in London, England.

ZB-1 VESSEL TEST
October 1-8 and October 16-23

The first period was directed to finalizing preparations for start of the ZB-1 vessel test. The AE system had been set up and functioned very well. A problem which delayed actual start of the test developed upon initial pressurization on 10/7/82. One of the vessel penetrations for COD gauge lead wires leaked at the fitting-to-vessel joint. Since it appeared that the tapped hole in the vessel was slightly out of true, the problem was solved by removing the one COD gauge for the present, and plugging and backwelding the hole.

The first attempt to perform the Step 1 hydro test to 240 bars took place on 10/12/82. A maximum pressure of 130 bars was reached. At this point, the pressurizing system developed problems and the test was halted. In the latter stages of the test, high amplitude AE was detected from the KS07 insert. This tended to focus on a weld across the center of the insert. Similar data was observed by the KWU test team. Only scattered, low amplitude AE was observed from the A533 insert which is as expected. The flaws saw greater stress during precracking so would not be expected to emit.

Battelle

The test efforts were shut down 10/13, 14, and 15 due to Rainer Gillot's participation in the MPA Fracture Mechanics/Nondestructive Testing Seminar.

A meeting was held at MPA in Stuttgart on 10/18/82 to discuss ZB-1 test status and any problem areas. In attendance were:

| | |
|---|---|
| Dr. Kussmaul | - MPA |
| Mr. Gillot | - MPA |
| Mr. Sturm | - MPA |
| Mr. Meyer | - MPA |
| Dr. Muscara | - NRC |
| Mr. Kurtz | - PNL |
| Mr. Hutton | - PNL |

Major topics were:

- Baseline NDI of the ZB-1 Vessel

  The testing was performed partly by Izfp at Saarbrucken and partly by MPA at Mannheim. The results have not yet been assembled into a report. No date for completing the report could be established since no Izfp representatives were at the meeting.

- Periodic NDI of the ZB-1 Vessel

  MPA was planning to do three inspections of the vessel including the baseline. NRC and PNL expressed the need for NDI following each hydro at least for the Phase 1 (NRC/PNL) portion of the test. This was agreed to by MPA with an expressed willingness to do additional inspection at special points in the test if justified.

- Limited Participation in the ZB-1 Test by Harwall (Chris Scruby)

  As discussed under the section of this report concerning business in the U.K., it appeared there was merit to arranging for Harwell to participate in the ZB-1 test on a limited scale to obtain data samples to relate to their basic laboratory studies on predictive characterization of AE signals. Dr. Kussmaul did not express any generic objection to this. The matter was left on the basis that if a test plan to be generated by Harwell was acceptable to PNL and NRC, it would then be submitted to MPA (Dr. Kussmaul) for approval.

Battelle

- Covered Entry for Instrument Trailer at Mannheim

  Construction of an enclosed entry attachment to the instrument trailer at Mannheim had been requested earlier. This is needed to help minimize the influx of coal dust into the trailer and thus promote operating continuity of the instrument systems (disk drives, terminals, etc.). Gillot agreed that the entry would be built as soon as the appropriate person at GKM returned from vacation in about two weeks.

- ZB-1 Vessel Test Schedule

  The initial hydro would again be attempted Wednesday or Thursday of this week (10/20 or 21). A different pressurizing pump was to be moved from MPA to Mannheim to help solve the pressurizing problems.

- Integrity of the KS07 Insert

  The initial question posed was, "What course of action is planned if the KS07 insert fails?" MPA shares our concern over the integrity of the KS07 insert. They are considering installation of "strongbacks" over the insert as well as replacement of the insert with sound material. Neither "strongbacks" or a replacement insert are on hand or in fabrication. Replacement of the insert would obviate MPA's original purpose in performing this test. They would, however, still have all data generated from our insert.

  The key concern which surfaced was the possibility that failure of the KS07 insert might result in effective loss of the whole vessel. PNL was charged with the responsibility for using AE to insure that the KS07 did not reach failure. The objective is obviously essential and we definitely plan to exert our best efforts, but I was quite concerned that we could not guarantee attaining that objective. This does not suggest that we doubt the ability of AE monitoring, but the KS07 insert represents materials that would never be found in a reactor. We have already demonstrated in the laboratory that with the high density of random cracks in the material, a sensor 10 inches from a growing crack may receive no AE because of an intervening crack field. The initial hydro effort would suggest this may not occur with the KS07 insert, in which case, impending failure can be detected by using AE to assess whether crack arrest occurs or not at pressure hold. The hydro pressurization is approached in increments after the onset of AE

Battelle

that begins to focus at a location(s) with a hold at pressure of 5-10 minutes before the next pressure increment. The AE should stop with pressure hold if the crack is arresting. If the AE continues during pressure hold, the crack is not arrested at that pressure and could go to failure with any further pressurization. A rapid increase in AE rate is another indication of impending failure. The above techniques can be used with confidence if all of the AE sensors can receive the AE signals - i.e., they are not shielded from the AE by other cracks.

Discussion then shifted to the fact that a 100 mm thick compact tension specimen of the degraded KS07 material would be tested by MPA in two-three weeks. This was considered as a possible source of AE/material characterization information that might benefit surveillance of the vessel insert (KS07). The specimen may be tested either at MPA, Stuttgart, or in the test bunker at GKM, Mannheim. We have the equipment capability to monitor it at either location and plan to do so.

The next two days (10/19, 20) were devoted to improving the vessel pressurizing system, examining data from the first attempt at pressurization (10/12), and defining detail points of the test plan.

A second attempt to perform the Step 1 hydro to 240 bar took place on 10/21. Since the previous hydro went to 130 bar, pressurizing was essentially constant to 140 bar with the exception of a brief delay at 120 bar due to pressurizing system problems. Moderate AE was detected from KS07 at 140 bar but rapidly diminished with pressure hold. The next step went to 150 bar and again AE died off on hold. The AE rate was starting to increase between 150 and 165 bar but the AE stopped quickly at 165 bar pressure hold. At this point, the pressurizing system developed a leak which made further pressurization impossible.

On 10/22 the leak in the pressure system was found and repaired. The Step 1 hydro was resumed for the third time. AE from KS07 was again detected at about 165 bar (previous high pressure). Up to 200 bar, the AE died off on pressure hold. Starting at 200 bar, two things happened which caused much concern:

- When pressure was held at 220, 225 and 230 bar, the AE continued with little change.

Battelle

- Between 200 and 230 bar, seven or eight very audible "pop-ins" were heard through a microphone located near the KS07 insert.

The unanimous decision was made to stop the test at 230 bar. The KWU monitoring team was showing very similar results and agreed that they too were concerned that the KS07 was rapidly approaching failure.

A major portion of the AE was concentrated along the transverse center weld in the KS07 but there were also two locations in the body of the plate that began to show AE concentration.

During all of these tests, the A533-B insert showed only scattered AE indications. This is consistent with expectations considering prior flaw pressurization during precracking.

AE data is being analyzed in preparation for meetings the week of 10/25 to determine a course of action to allow the test to proceed.

NOTE: Telephone contact with Rick Kurtz and Dick Pappas during the week of 10/25 gave the following information:

- PNL and MPA people met at Stuttgart on 10/25 for preliminary review of test results. Kussmaul proposed to start Step 2 cycling with a maximum pressure of 200 bar for a short period. If this did not produce worrisome results, gradually increase the top pressure to 240 bar. This poses a problem; since the pressurization rate is about 70 times faster during cyclic loading, the reaction time to respond to an indication of impending failure is greatly reduced.

- A meeting of KWU, PNL, and MPA was scheduled for 10/27 to attempt to resolve a course of action.

- Kussmaul was not present at the 10/27 meeting at MPA. Among those present (Gillot and Strum, MPA; Kurtz and Pappas, PNL; Jax and Basoukis, KWU), there was agreement that the KS07 insert should be replaced prior to any more testing. NDI will be performed on the insert to attempt to gain further information. KWU agrees totally with PNL AE results from the hydro test and concur that the plate appeared to be near failure.

Battelle

Gillot now estimates 6-12 weeks to replace KS07 insert. A key factor, however, is funding source. If the funds come initially from MPA, the 6-12 weeks is probably valid. If the funds must come initially from the government, the delay could be much longer. The ultimate decision still rests with Dr. Kussmaul. The identifiable action items are:

1) MPA will perform magnetic particle inspection of the outside of the KS07 insert and dye penetrant inspection of the inside on Friday, 10/29.

2) RTD (inspection group from the Netherlands) will start a phased array ultrasonic inspection of the KS07 insert on 11/3. This is expected to require three days.

3) PNL personnel will remain at the test site and work on data analysis, etc. anticipating a definitive decision by 11/5 or 8.

4) I will contact you (Joe Muscara) as soon as possible to discuss our position on the future direction of this test.

CONFERENCE ON PERIODIC INSPECTION
OF PRESSURIZED COMPONENTS AND
OTHER BUSINESS - LONDON
October 9-15

Relatively basic investigations of AE from crack growth and plastic deformation in metals are being conducted at Harwell Laboratory. This work was reviewed on 10/11 in a meeting with C. Scruby and A. Wedgewood. They have developed a theoretical prediction of the analog signal components that should be produced at a sensor by the various source mechanisms (crack growth, slip, twinning, etc.). They have succeeded in demonstrating these predicted signal features on controlled laboratory specimen tests. They are very interested in obtaining a data sample from the ZB-1 test using their own instrumentation to determine if the theory can also be demonstrated on a large structure. There appears to be some possible benefit to the NRC program from this work in the area of signal characterization. Harwell proposes to perform the work and make the results available to us at no cost to our program. The topic was discussed further during a meeting of Scruby, Wedgewood, Muscara and Hutton on 10/15. The action defined was for Harwell to prepare a written test plan or proposal for review by PNL and NRC. If this plan meets our approval, it would then be presented to Dr. Kussmaul, MPA for final approval.

Battelle

The balance of the week (10/12, 13, 14) was devoted to the Conference on Periodic Inspection of Pressurized Components. I presented a paper titled "Accustic Emission and Estimation of Flaw Significance in Reactor Pressure Boundaries" on 10/12. A copy of the paper is attached.

It should be noted that the trip was extended two days beyond the original plans in order to be present during the Step 1 hydro testing.

Please contact me if you wish further detail on any aspect of the trip.

Yours very truly,

P. H. Hutton

P. H. HUTTON
Project Manager

PHH:kw

Attachment