REPORT No. N88-283-FR1
DATE February 1989

FINAL REPORT

**DEVELOPMENT OF AN INSPECTION SYSTEM FOR THE REACTOR VESSEL/CONTAINMENT
VESSEL OF THE PRISM AND SAFR LIQUID METAL REACTORS**

Prepared for the
United States Department of Energy
Under Contract No. DE-AC03-88SF17470

APPLIED TECHNOLOGY

~~Any further distribution by any holder of this document or of other
data therein to third parties representing foreign interests, foreign
governments, foreign companies and foreign subsidiaries or foreign
divisions of U.S. companies should be coordinated with the Director,
"Appropriate NE Program Office," U.S. Department of Energy.~~

This document is
PUBLICLY RELEASABLE

Leonard P. Phillips, Jr. ORNL

Authorizing Official

Date 1-3-13

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TABLE OF CONTENTS

ACRONYMS	ii
EXECUTIVE SUMMARY	iii
SECTION 1 - INTRODUCTION	1
1.1 Specifications of Resulting System	2
SECTION 2 - DEVELOPMENT OF CAMERA AND CONTROL SYSTEM	3
2.1 Design Considerations	3
2.2 System Design	4
2.3 Testing and Validation	5
SECTION 3 - DEVELOPMENT OF MOCK-UP AND HEATING CONTROLS	11
3.1 Design Considerations	11
3.2 Mock-up Construction	11
3.3 Evaluation and Testing	13
SECTION 4 - TESTING AND VALIDATION	14
SECTION 5 - SUGGESTIONS FOR FUTURE DEVELOPMENT	17
5.1 Improvements to the Camera Housing	17
5.2 Camera Positioning Device	18
5.3 Video Image Enhancements	19
APPENDIX - TEST PROCEDURES	A-1

List of Figures

Figure 1. Video Inspection System	1
Figure 2. Camera Assembly	4
Figure 3. Camera And Housing Assembly	5
Figure 4. Sample Test Region	6
Figure 5. Samples on Commercial Surface (with Reflector)	7
Figure 6. Samples on Blackened Surface (with Reflector)	8
Figure 7. Samples on Commercial Surface (No Reflector)	9
Figure 8. Samples on Blackened Surface (No Reflector)	10
Figure 9. Schematic Representation of Mock-Up	11
Figure 10. Location of Thermocouples Within the Mock-Up	12
Figure 11. Complete Mock-Up Showing Heater Control Rack	13
Figure 12. Image of 1.6 mil Wire; (a) Before Heat-up, (b) After 45 Minutes In-Annulus	14
Figure 13. Image Quality 60 Minutes In-Annulus	16
Figure 14. Image Quality of 0.032" Wire @ 71°C	16
Figure 15. Image Quality of 1 mil wire @; (a) 53°C, (b) 97°C	17
Figure 16. Camera Housing - Improved Design	18
Figure 17. Camera Positioning Device Concept	19
Figure 18. Digital Image Enhancement - Block Diagram	20

List of Tables

Table 1. System Design Criteria	3
Table 2. Effect of Temperature Control Methods on Operating Time	15

ACRONYMS

CCD	Charge-Coupled Device
CCTV	Closed Circuit Television
PRDA	Program Research Development Announcements
PRISM	Power Reactor Inherently Safe Module
SAFR	Sodium Advanced Fast Reactor
TC	Thermocouple
TV	Television
VCR	Video Cassette Recorder
DOE	Department of Energy

EXECUTIVE SUMMARY

The integrity of the reactor vessel is of utmost importance in both the PRISM and SAFR concepts. The reactor vessel operates at elevated temperatures and contains molten liquid sodium. To ensure safe operation of the reactor, a periodic, visual inspection of the walls of the containment vessel is required by ASME specifications. This inspection would be conducted during a time when the reactor is shut down for refueling or maintenance.

Nuclear Systems Associates, Inc. (NSA) was issued a PRDA contract by the Department of Energy to design, develop, and test a Closed Circuit Television (CCTV) camera system. The purpose of the system is to inspect the welds and wall surface of the Reactor Vessel/Container Vessel for both the PRISM and SAFR type reactors. The system was designed to function at the reactor's normal shutdown temperature, and provide a clear indication of flaws in the wall's weld seams and any cracks that might develop.

The project was performed in three phases. The first phase concentrated the efforts on producing a compact camera system with the required resolution, self-contained lighting, and remote control focus and viewing angle. The proposed camera was then tested in a vessel mock-up and found to perform to required specifications at room (cold) temperatures. Simulated flaws, cracks, and a sodium leak were observed with required clarity on both a commercial and blackened stainless steel surfaces. The camera was tested with a single clear glass dome, a single coated glass dome, and a dual-glass dome covering the camera lens and mirror.

The second phase of the project was conducted in two parts. The first part involved testing the vessel mock-up at elevated temperatures to verify that the required temperatures can be obtained. The mock-up was constructed with imbedded heaters and both control and indicating thermocouples. Stable operating temperatures over 400°F were achieved.

During the second part of this phase, the camera was inserted into the heated mock-up to verify proper operation at elevated temperatures. Several methods were employed to maintain a temperature within the camera assembly below the camera's maximum rating. In the final configuration, the in-annulus time of the camera substantially exceeded requirements. Picture resolution and clarity were not compromised.

In the final phase, the camera was subjected to increasing temperatures within the mock-up until image degradation was observed. This occurred at a camera temperature significantly above the rated value. The camera was then returned to the manufacturer for a complete factory evaluation of any permanent damage. Their report indicated that no discernible damage had occurred.

Suggestions are offered for further refinement of the techniques described in this report. One improvement is the use of digital image processing to readily detect cracks and flaws, and to objectively compare the current surface condition to that of a previous inspection.

SECTION 1. INTRODUCTION

In both the PRISM and SAFR concept reactors, the ASME code requires a visual examination of the longitudinal and circumferential shell welds on the reactor and containment vessels. This visual inspection is one that must be conducted so that the presence of liquids, liquid streams, drops, and smoke are discernible. The inspection would be conducted during a shutdown, when the vessel temperatures are approximately 400°F.

A dry annulus between the Reactor and Containment vessels exist in both type reactors. However, the small (5-inch) size of the annulus in the PRISM design was the limiting factor on the size.

Another problem is the elevated temperature of the annulus (400°F). Commercial, state-of-the-art TV cameras can withstand a maximum temperature of only 120°F to 140°F. Fiber optic bundles have a maximum temperature of 350°F.

This report describes results of the development of a compact video camera system by Nuclear Systems Associates, Inc. (NSA) that will operate at the required temperatures and fit into the annulus of both the SAFR and PRISM reactors.

After much evaluation, a Charge Coupled Device (CCD) camera was chosen, which utilized a rotating mirror and protective dome located in front of the camera's lens. This design (Figure 1), provided complete remote-control of the focus and area of view of the camera. All sensitive electronics are located in the control cabinets to minimize heat exposure.

Figure 1. Video Inspection System

1.1 Specifications of Resulting System

Physical:

Camera Dimensions
Weight

3.75" Dia. x 11" L (9.53 x 27.94 cm)
5 lbs. (2.27 kg)

Design:

Imaging technology
Focus range
Viewing angle
Insulation

Charge-Coupled Device (CCD)
Remote-controlled, 1 to 5 inches
Remote-controlled, 0 to 360°
Double-walled housing round camera
Double-glass dome over lens

Operating temperature (within the camera)

10°C to 71°C (50°F to 159.8°F)

Operation period (@ 400°F)

1 hour, 20 minutes

Temperature monitors

Thermocouples in dome, camera
body, and camera housing.

External Cooling not Required

SECTION 2. DEVELOPMENT OF CAMERA AND CONTROL SYSTEM

The first part of this project required the evaluation of the intra-annular environment and the specifications of commercially available equipment. From these data, a proposed specification was developed, and the equipment designed as required, to meet that specification. The desire was to utilize as many commercially available devices as possible.

2.1 Design Considerations

Several criteria were crucial to the design of the video inspection system. As stated in the Introduction, the inspection system must be small enough to navigate the 5-inch annulus of the PRISM reactor, and it must be able to operate in a 400°F environment for up to one hour. The one hour period is the estimated time required to adequately navigate and inspect the walls of the annulus, based on the dimensions of the PRISM concept. During the inspection, the system must also discern a typical crack that is as small as 3 mils (.003") in width. This resolution must be obtained on both a commercial stainless steel surface as well as one that has been blackened for high thermal emissivity.

Several commercially available video camera designs were considered. These include the standard vidicon and the newer Charged Coupled Device (CCD) cameras. Although the vidicon camera has proven itself in high radiation environments such as Hot Cell monitoring, its physical dimensions precluded its incorporation in the proposed system. The problem was that it was too long to move within the curvature of the annulus while suspended from an umbilical cord. The ideal length for this system is less than 12-inches, including housing, lens, and directional control. Applicable commercial cameras employing the vidicon tube have a minimum length of 15-inches. Since radiation levels were not a concern in this application, and manufacturers of this type of inspection camera were reluctant to modify their designs as required, the vidicon was removed from consideration.

Table 1 lists the design criteria for the proposed inspection camera system.

TABLE 1. SYSTEM DESIGN CRITERIA

Operating Temperature	400°F
Limiting Annular Space	5-inches (PRISM)
Control Cable Length	100 feet
Intra-Annular Lighting	Provided by the camera
Image Resolution	0.003-inches

Inspection cameras which utilize Charge-Coupled Device (CCD) technology are becoming popular due to their compact size, high resolution, and low power requirements.

Using the criteria of small size and low power requirements, a camera system was developed around the CCD. Another advantage of this device is that the majority of the electronics may be located several meters away from the camera without loss or corruption of the signals.

2.2 System Design

A small camera with remote control focus and a rotating mirror in front of the lens was chosen as the basis for the design. The camera assembly and housing were designed by NSA. The camera was built to NSA's specifications by a manufacturer of custom, high quality television cameras. This concept has been used for inspection of deep oil well bores. The rotating mirror provides the ability to scan the surface of the containment walls while keeping the camera at a fixed orientation. The camera assembly is shown in Figure 2.

Figure 2. Camera Assembly.

In order to insulate the camera from heat and shock, a double-walled case was designed to enclose the camera. This housing, shown in Figure 3, contains the camera, preamplifier, and primary lens. The double-walled design restricts heat transfer to the camera. The light bulb was located outside the enclosure so as not to add heat to the internal area of the camera. The lens, mirror, and mirror drive motor are enclosed in a glass dome.

To provide temperature readout of the assembly while in the annulus, thermocouples are located within the dome, and between the housing walls. A temperature sensor was built into the camera by the manufacturer to monitor the temperature of the CCD element. An umbilical cord containing power and signal cables, and gas tubing connects the camera assembly to the power and control electronics. The umbilical cord is sheathed with flexible metal hosing to prevent damage to the wires and tubing.

Figure 3. Camera And Housing Assembly.

A remote control chassis contains the control circuits and switches used to focus the lens and rotate the mirror so that different portions of the area around the camera may be examined. Three-position switches are used so that the functions may be reversed or stopped. A digital (LED) meter on the control panel indicates the temperature (in °C) of the camera unit at all times. A second panel provides the required control for the operator to turn the light in the camera dome on and off and vary the intensity. This provides optimum lighting for all surfaces.

2.3 Testing and Validation

In order to test the camera assembly, a 7 ft high x 9 ft circumference (full-scale) mock-up was constructed that represents a segment of the Reactor Vessel/Containment Vessel. The mock-up includes heaters and controlling thermocouples so that reactor shutdown temperatures may be simulated.

A sample test region (Figure 4) was defined which simulated various types of flaws, including a sodium leak. Different diameter wires were used to simulate weld flaws between 1 and 32 mil diameter (0.001 to 0.032-inch). A 0.005-inch scratch was also made in the plate. A portion of this sample region was blackened to simulate a high thermal emissivity coating. The samples (1 to 32 mil wires and scratch) were duplicated over this portion of the region to determine the difference in camera performance if the vessel incorporates the high thermal emissivity coating for better heat transfer. The two sample sets were separated by a 0.005-inch scratch filled with a dried refractory oxide to simulate the results of a sodium leak.

Figure 4. Sample Test Region.

Several configurations of the camera assembly were tested to determine the difference (if any) in resolution between:

- Using a reflector behind the illumination source.
- Covering the camera lens with a clear glass dome.
- Covering the camera lens with a semi-reflective glass dome.

For each configuration, the camera was placed in the mock-up and the samples examined. Video tapes of each sample under each of the three conditions were made for later evaluation. Each of these tests are described in Section 1 (Cold Tests) of the Appendix. We found the cameras had excellent resolution; more than could be expected from the specifications.

Figure 5 shows the images obtained with the 0.032-inch, 0.003-inch, and 1.6 mil wires and the 0.005-inch scratch on a commercial surface. Figure 6 shows the same sample on the blackened surface (BSS). Note that all samples are clearly visible. These photographs were taken with the reflector mounted behind the lamp.

Figure 5. Samples on Commercial Surface (with Reflector).

Figure 6. Sample on Blackened (BSS) Surface (with Reflector).

In Figures 7 and 8, the same samples were photographed without the reflector. As demonstrated, an improvement is obtained when the reflector is utilized. Note that the lower light intensity at the surface results in less visibility of the samples below 0.003-inches.

Figure 7. Samples on Commercial Surface (No Reflector).

Figure 8. Sample on Blackened (BSS) Surface (No Reflector).

In Figures 5 through 8, the 1.6 mil wire is visible. The 0.001" wire was visible except in the blackened surface. The anticipated lower-end size of a weld crack is 1 to 3 mil. Figures 5 through 8 show this ability of the system to resolve weld flaws of these dimensions.

Both clear glass and semi-reflective glass domes were evaluated for image quality. No differences were observed.

SECTION 3. DEVELOPMENT OF MOCK-UP AND HEATING CONTROLS

3.1 Design Considerations

As noted in the previous section, a mock-up of a reactor vessel/containment vessel with annulus had to be constructed to properly test the video inspection system. Requirements for the mock-up are (1) it must be a full-scale model of a segment from a reactor vessel/containment vessel, and (2) it must maintain internal (intra-annular) temperatures consistent with those encountered during an inspection or refueling shutdown.

3.2 Mock-Up Construction

Using these criteria and the most restrictive specifications (PRISM concept), the mock-up was constructed using stainless ("reactor") and carbon ("containment") steel plates. The annulus width was set at 5-inches and the radius of curvature for the segment was consistent with that of the PRISM concept. Figure 9 shows a cross-section view of the design.

Figure 9. Schematic Representation of Mock-Up.

The samples described in Section 2.3 were fastened to the wall on the annulus side of the "reactor vessel." Four heaters and thermocouples were fastened to the inner side of the "reactor vessel" wall. Additional thermocouples were placed at each of 17 locations within the annulus as shown in Figure 10. A fiber glass-type of insulation was then placed over the entire mock-up to minimize heat loss.

Figure 10. Location of Thermocouples Within the Mock-Up.

Four of the thermocouples were connected directly to the heater control units to regulate the mock-up temperature. The remainder of the thermocouples were connected to a readout module through a selector switch, and used to read the temperature at various locations in the mock-up. The schematic diagram of this heater control/readout system is shown in Figure 10. Figure 11 is a photograph of the completed mock-up showing the heater control rack.

Figure 11. Complete Mock-Up Showing Heater Control Rack.

3.3 Evaluation And Testing

The principle concerns in the design of the heater controls were that they allow the mock-up to reach operating temperature (400°F in the annulus) within a reasonable amount of time, and that the heaters are not operated beyond their maximum temperature ratings. In the initial configuration, the thermocouples located between the wall and the heater pads were used as indicators to ensure the pads were not heated to an unsafe level. Four other thermocouples in the annulus were connected directly to the heater control units to regulate the heater temperature.

After considering the thermal transfer properties of air within the annulus and the heat capacity of steel plate, the heater controller system was reconfigured. The thermocouples located underneath the heater pads were connected directly to the controllers and those in the annulus were assigned to readout functions. Using this arrangement, when the heater controls were set to the proper value, and the temperature in the annulus was measured with time, a steady rise was observed. After approximately four hours, the temperature in the annulus began to level off to the desired 400°F.

Once the correct location for the controlling thermocouples was established, a series of tests were conducted to ensure the heater controls would perform properly. These tests then determined the proper temperature for the heaters to produce the required 400°F temperature within the annulus. The details of these tests are described in the Appendix under Section 2.

From these data, all experiments utilizing the camera system at operating temperatures were performed only after a heating period for the mock-up of approximately 6 hours.

SECTION 4. TESTING AND VALIDATION

Once the mock-up and heater controls were tested, the last phase of this work was to evaluate the performance of the camera system at elevated (typical reactor shutdown) temperatures. The primary concerns here were that the camera not lose optical resolution at the elevated temperatures, and that its internal (camera) temperature remain below the specified maximum (60°C) during the inspection period. Using the dimensions of the PRISM concept, we calculated that the total in-annulus time would be approximately 60 minutes. This should provide sufficient time to adequately inspect all weld seams within the annulus.

In all experiments, the mock-up was preheated for approximately 6 hours before lowering the camera into the annulus. As described in the Appendix, Section 4 (Hot Tests), four temperatures were monitored while the camera was in the mock-up. These are T1 - temperature of the camera CCD element, T2 - temperature between the walls of the camera enclosure, T3 - temperature inside the dome over the lens, and T4 - the annulus temperature. Temperature T1 is displayed on the camera control panel and is the main factor in determining the total operating time period.

While in the annulus, the camera was used to display and record (on videotape) one of the eleven "flaws" on the sample plate. During the test period, the mirror-rotate and auto-focus adjustment were periodically exercised to ensure that they were still functioning properly. Various schemes were evaluated to increase the total time the camera could remain in the annulus without exceeding the maximum temperature. Tests 4.1 through 4.3 (Appendix) detail the procedures that were followed.

In all experiments, the picture quality and resolution did not degrade from those taken with the mock-up at room temperature. Figure 12 shows the 1.6 mil wire viewed at the beginning of the test and when T1 reached 60°C.

Figure 12. Image of 1.6 mil Wire; (a) Before Heat-up, (b) After 45 Minutes In-Annulus.

The maximum time obtained during these experiments was just over 45 minutes. The temperature within the camera at this point was 60°C (the maximum stated by the manufacturer). It was clear that a design modification was required to increase this time to 60 minutes as required by the design criteria.

Attempts to use active cooling by passing compressed gas (N₂) through the camera actually increased the temperature of the camera. This heating was the result of the gas being preheated during its passage through the umbilical cord. The next experiment involved the use of a dual glass dome over the camera lens without using the cooling gas. Theoretically, the air between the layers in the dual dome would provide an insulation blanket and keep the camera temperature down.

After replacing the dome over the lens and mirror, the experiments described in section 4.4 of the appendix were conducted. Although some improvement was noted, the elapsed time within the annulus was below the required 60 minutes. Table 2 shows the total elapsed time obtained with the camera using various cooling and insulating methods.

Questions were raised regarding the amount of heat generated by the camera itself. An experiment was conducted in which the camera was placed in an insulated container with the power turned on. The temperature (T₁) was found to remain below 33°C for several hours. This verified that most of the observed heating was caused by the temperature of the annulus, and that improved insulation would be beneficial.

A final, successful approach was obtained when the entire camera assembly was wrapped with a metallic foil. This foil provided a third wall around the enclosure and reduced heat transfer through the single wall rear panel of the enclosure. As shown in Table 2, the total time in-annulus was 61 minutes.

TABLE 2. EFFECT OF TEMPERATURE CONTROL METHODS ON OPERATING TIME

Method Used	Elapsed Time (minutes)		Dome (°C)	Camera (°C)
Single dome:				
No cooling used	28	aborted due to excessive temp. rise	78	60
Int and Ext cooling	20			
Pre-cooling	36		75	60
Double dome:				
Pre-cooling	47.5		70	60
Constant cooling	35		60	60
Foil wrapped housing	61		72	61.5
	81		79	71.0

The data shows that although an increase in the operating time can be obtained with some degree of pre-cooling, a corresponding increase in temperature is also noted. Best results were obtained by the addition of a "third wall" to the camera enclosure, thereby increasing the level of thermal insulation.

Figure 13 is a photograph of the 0.032" wire obtained from the system with the double dome and foil heat shield. As shown, there is no degradation of the image quality even after 60 minutes in the annulus.

Figure 13. Image Quality 60 Minutes Im-Annulus.

In a final experiment to determine maximum operating time, the camera manufacturer was consulted regarding the absolute thermal rating of the device. Using the final configuration of the camera system and the manufacturer's maximum temperature of 71°C, the experiment was repeated. In this test, a total time of approximately 80 minutes (1 hour, 20 minutes) was reached before the camera temperature reached the 71°C limit. As shown in Figure 14, even at this temperature, little if any degradation in image quality is observed.

Figure 14. Image Quality of 0.032" Wire @ 71°C.

An additional series of tests was conducted to determine the effects of exceeding the temperature rating of the camera, and if any damage would be incurred in the event that the condition was continued. The goal of these tests was to determine the ultimate functional capabilities of the camera system. Therefore, the smallest sample (1 mil wire) was observed during the tests described in the Appendix, Section 5.

Initially, the camera was kept in the annulus until the temperature in the camera reached 85°C (elapsed time of 95 minutes). Since no deteriorating effects were noted in the image quality, the tests were continued until the camera temperature reached 90°C. Even at this point, the only effect was the appearance of some faint white "dots" on the monitor. The image of the sample was still clear, and the Focus and Mirror controls continued to operate normally. When the camera was removed from the mock-up, the dome temperature was 208°F and the elapsed time was 107 minutes.

The next test was intended to push the camera to its "destruct-temperature." The image quality remained good until the temperature in the camera reached 97°C. At this point, the picture began to fade, and at a camera temperature of 97.2°C (elapsed time of 2 hours, 32 minutes), the picture dissolved to white in a few seconds. The camera was immediately removed from the annulus and cooling gas applied. After a few minutes of cooling, the camera was again able to function. The dome temperature during this test had reached 211°F. In the course of this test, faint white dots were noted on the image as described above. When the base light was turned off (camera temperature of approximately 80°C), the white dots presented a dim image of a "starry sky." As before, these dots did not detract from the image quality of the sample when the light was on.

In an effort to determine the residual effects (if any) of the overheating, the test was repeated. As shown in Figure 15, the image quality was retained until the picture faded at a temperature of 97.5°C. As before, when cooling gas was applied, the picture returned.

Figure 15. Image Quality of 1 mil wire @; (a) 53°C, (b) 97°C.

To determine the extent of any permanent damage to the camera, it was returned to the manufacturer for an complete evaluation. The camera passed all tests and retained the original factory specifications.

Section 5. SUGGESTIONS FOR FUTURE DEVELOPMENT

This project involved the establishment of design criteria for an intra-annular video inspection system, and the development of that system. The results of this study produced a prototype system that meets the following, established criteria.

- Fits easily into the annulus of the PRISM and SAFR concept reactor
- Will resolve a weld flaw or sodium leak of less than 0.003-inch width
- Operates in an environment of 400°F for up to 1 hour, 20 minutes.

Three additional areas should be considered for further projects. These are: improving the camera housing, motion of the camera within the annulus, and image enhancement.

5.1 Improvements to The Camera Housing

In the course of this work, a metallic foil "skin" was added to the body of the camera housing to maintain the internal temperature below 60°C while in the annulus. In addition, the dome covering the lens and mirror consisted of two domes separated by air. These required modifications recommend the following design change.

The dome might be constructed like a vacuum thermos bottle to further insulate the lens, mirror and motor. This should provide an improvement over the current dual-glass dome used in this study.

In addition, evacuating the space between the walls of the camera housing might provide the required insulation without the need for the third (foil) layer. If evacuation of the space is not sufficient, then a third wall may be added to the housing.

Because of problems encountered in using compressed N_2 , the gas tubing in the umbilical cord should be removed. The housing should then be modified with internal plumbing and external fittings to allow connection of a gas source to the camera after it is removed from the annulus. This scheme would provide for cooling the camera (by gas flow) immediately upon removal from the annulus. Figure 15 shows the recommended design change.

Figure 15. Camera Housing - Improved Design.

5.2 Camera Positioning Device

During this project, the mock-up was constructed with a track inside the annulus on which the camera traveled between samples. In later evaluations (after the start of the project), an objection was raised based on the potential problems associated with the welding of the track structure to one containment vessel.

In order to accurately position the camera within the annulus, some type of positioning device must be attached to the camera housing. One suggestion is a robot "spider" which will hold the camera and move about the annulus by using expanding "legs" to position itself securely between the walls. Figure 16 is a view of this conceptual device.

Figure 16. Camera Positioning Device Concept.

5.2 Video Image Enhancement

In the Camera Development Section of this report, the photographs show a loss of definition when the sample approached 1.6 mil (0.0016-inches). Although this is almost half the expected size of a weld flaw, image resolution beyond this value may prove invaluable in the detection and prevention of developing flaws.

A secondary criteria for choosing the CCD-type camera was the fact that the CCD is readily suited for digital image processing for video enhancement. Such techniques applied to other disciplines can result in an up to ten-fold increase in the visual resolution of an image.

Digital image processing can be used to establish an objective method of inspection that compares to the original condition of the vessels with the condition at a later time. In this manner, the flaws or defects that occurs between inspections can be readily found. Using the current equipment configuration, with a digital storage technique to store images, the image may be processed at a later date to obtain the benefits of this enhancement. Figure 17 shows a typical equipment configuration block diagram.

Figure 17. Digital Image Enhancement - Block Diagram.

APPENDIX - TEST PROCEDURES

Purpose of Tests	A-2
Section 1 - Camera Operation (Cold Tests)	A-2
1.1 Camera with Base Lighting Reflector	A-2
1.2 Camera Without Base Lighting Reflector	A-2
Section 2 - Heating Control Operation.....	A-5
2.1 Heat Controller and Thermocouples.....	A-5
2.2 Determine the Temperatures at the Camera Locations.....	A-6
Section 3 - Camera Resolution Using the Plated Dome.....	A-7
3.1 Camera With Base Lighting Reflector.....	A-7
3.2 Camera Without Base Lighting Reflector	A-7
Section 4 - Camera Operation (Hot Tests).....	A-10
4.1 Evaluate Operation of Coolant System.....	A-10
4.2 Determine Maximum Operating Period Without Coolant.....	A-10
4.3 Determine Maximum Operating Period With a Pre-Cooled Camera	A-11
4.4 Determine the Effect of an Insulated Dome	A-11
Section 5 - Determine the Effect of Exceeding Maximum Temperature.....	A-13
List of Equipment Used	A-14

Figures

Figure A-1. Camera Assembly With Reflector.....	A-3
Figure A-2. Test Fixture and Equipment	A-3
Figure A-3. Test Sample Region	A-4
Figure A-4. Camera Assembly - Reflector Removed.....	A-4
Figure A-5. Heater Control System Schematic.....	A-5
Figure A-6. Camera Location Temperature Sensors	A-6
Figure A-7. Test Fixture and Equipment	A-8
Figure A-8. Test Sample Region	A-9
Figure A-9. Camera Assembly - Reflector Removed.....	A-9
Figure A-10. Location of Camera Temperature Sensors.....	A-11

Purpose of Tests

The following test procedures were used by Nuclear Systems Associates, Inc. to evaluate the equipment designed under DOE Contract No. DE-AC03-88SF17470. This project was designed to develop an inspection system for use in the annulus of a reactor containment vessel. The inspection system will allow the accurate location and evaluation of the interior wall of the containment using a video camera.

These tests demonstrated the performance of the system during its development, and verified operation under simulated operating conditions.

Section 1 - Camera Operation (Cold Tests)

This series of tests are designed to demonstrate the image quality of the camera with and without using the lighting reflector on the camera assembly.

Test 1.1 - Camera with Base Lighting Reflector.

1. Insert the camera (Figure A-1) into the test fixture as shown in Figure A-2.
2. Position the camera at the first sample (Figure A-3), and adjust the lighting and focus for the best definition of the sample.
3. Start the recorder and use the video-writer to inscribe the date. Next, rotate the camera mirror to scan from the bottom to top of the sample. Stop the mirror at one end showing the sample number.
4. After 30 seconds, press PAUSE on the recorder and move to the next sample. Press the PAUSE button to continue recording.
5. Use the video-writer to inscribe the following information on the tape:
 - Simulated Flaw #, wire size or scratch
 - Surface (commercial stainless or blackened surface)
6. Move the camera to the next sample and repeat steps 3 through 5. Repeat for all samples.

Test 1.2 - Camera Without Base Lighting Reflector.

1. Remove the base lighting reflector shown in Figure A-3.
2. Insert the camera into the test fixture as shown in Figure A-2.
3. Position the camera at the first sample, and adjust the lighting and focus for the best definition of the sample.
4. Start the recorder and rotate the camera mirror to scan from the bottom to top of the sample. Stop the mirror at one end showing the sample number.
5. After 30 seconds, press PAUSE on the recorder and move to the next sample. Press the PAUSE button to continue recording.

6. Use the video-writer to inscribe the following information on the tape:
 - Simulated Flaw #, wire size or scratch
 - Surface (commercial stainless or blackened surface)
7. Move the camera to the next sample and repeat steps 3 through 6. Repeat for all samples.

Figure A-1. Camera Assembly With Reflector

Figure A-2. Test Fixture and Equipment

Figure A-3. Test Sample Region

Figure A-4. Camera Assembly - Reflector Removed

Section 2 - Heating Control Operation

These tests verify the ability of the mock-up to control temperatures up to 800°F. The temperature is raised in steps from 300° to 800°. Remove the camera from the mock-up before starting this sequence. Figure A-5 illustrates the equipment configuration used.

NOTE: The heater thermocouples must not exceed a temperature of 800°F.

Test 2.1 - Heat Controllers and Thermocouples.

1. Turn on the heaters and thermocouple control circuits.
2. Set the controllers for a temperature of 300°F.
3. Monitor all thermocouples, taking reading every 30 minutes until a steady state temperature is reached.
4. Repeat Steps 1 through 3, setting the controllers for the following temperatures:

Figure A-5. Heating Control System Schematic

Test 2.2 - Determine the Temperature at the Camera Locations

This test determines the temperature along the camera's path with the heaters at maximum temperature (800° F).

1. Turn on the heaters and thermocouple control circuits.
2. Set the controllers for a temperature of 800°F.
3. Monitor all thermocouples, taking reading every 30 minutes until a steady state temperature is reached.
4. Record the temperatures at the three camera location thermocouples as shown in Figure A-6.

Figure A-6. Camera Location Temperature Sensors

Section 3 - Test Camera Resolution Using the Plated Dome

These tests demonstrate the resolution of the camera (cold condition) when using a plated dome in place of the clear glass dome over the lens.

The mock-up is allowed to cool to ambient (room) temperature before proceeding.

This series of tests are designed to demonstrate the image quality of the camera with and without using the base lighting reflector on the camera assembly.

Test 3.1 - Camera with Base Lighting Reflector.

1. Insert the camera into the test fixture as shown in Figure A-7.
2. Position the camera at the first sample (Figure A-8), and adjust the lighting and focus for the best definition of the sample.
3. Start the recorder and rotate the camera mirror to scan from the bottom to top of the sample. Stop the mirror at one end showing the sample number.
4. After 30 seconds, press PAUSE on the recorder and move to the next sample. Press the PAUSE button to continue recording.
5. Use the video-writer to inscribe the following information on the tape:
 - Simulated Flaw #, wire size or scratch
 - Surface (commercial stainless or blackened surface)
6. Move the camera to the next sample and repeat steps 3 through 5. Repeat for all samples.

Test 3.2 - Camera Without Base Lighting Reflector.

1. Remove the base case lighting reflector shown in Figure A-9.
2. Insert the camera into the test fixture as shown in Figure A-7.
3. Position the camera at the first sample (Figure A-8), and adjust the lighting and focus for the best definition of the sample.
4. Start the recorder and rotate the camera mirror to scan from the bottom to top of the sample. Stop the mirror at one end showing the sample number.
5. After 30 seconds, press PAUSE on the recorder and move to the next sample. Press the PAUSE button to continue recording.

6. Use the video-writer to inscribe the following information on the tape:
 - Simulated Flaw #, wire size or scratch
 - Surface (commercial stainless or blackened surface)
7. Move the camera to the next sample and repeat steps 3 through 6. Repeat for all samples.

Figure A-7. Test Fixture and Equipment

Figure A-8. Test Sample Region

Figure A-9. Camera Assembly - Reflector Removed

Section 4 - Camera Operation (Hot Tests)

These tests simulate operation of the camera assembly under actual reactor temperatures. The ability of the camera to operate under these conditions, and the ability of the cooling system for the camera are evaluated. Figure A-10 illustrates the equipment configuration used.

Be sure the camera assembly is removed from the mock-up during heating.

Test 4.1 - Evaluate Operation of Coolant System

1. Turn on all heaters and set the control circuits for a temperature of 800°F. Maintain the 800°F temperature for a period of 7 hours before proceeding.
2. Install the camera into the mock-up and move it to a position where the temperature is 400°F.

NOTE

Temperature limits must not be exceeded. If any of the following limits are reached, remove the camera from the mock-up. Camera Unit - 140°F (60°C); Camera Housing - 140°F; Camera Dome Interior - 175°F.

3. Monitor the temperature of the camera every 3-5 minutes starting at time zero ($t = 0$). Record the temperature on the video recorder
4. Record the following temperatures:

T1 = Camera Temperature read at the camera control unit (read in °C).

T2 = Temperature of the Gap between the camera and camera housing. Read at Thermocouple readout position 15.

T3 = Temperature within the camera dome. Read at the thermocouple readout position 16.

T4 = Temperature within the mock-up at the camera location
5. If any temperature (except T4) reaches 125°F (51°C), turn on the internal camera coolant.

If the temperatures continues at 125°F (51°C), turn on the external camera coolant.

Record the type of coolant being used (Internal, External, Both) on the video tape.
6. If the camera temperatures remains at or below 130°F (54°F), continue testing for 1 hour, then remove the camera.

Test 4.2 - Determine Maximum Operating Period Without Coolant

1. Repeat Test 4.1, Steps 1 through 4.
2. When temperature T1 reaches 50°C, remove the camera and record the elapsed time.

Test 4.3 - Determine Maximum Operating With a Pre-Cooled Camera

1. Turn on all heaters and set the control circuits for a temperature of 800°F. Maintain the 800°F temperature for a period of 7 hours before proceeding.
2. Turn on the internal and external cooling gas for the camera and allow the temperature to stabilize.
3. Repeat steps 2 through 4 of Test 4.1. Be sure to observe the precaution on maximum temperatures.
4. When temperature T1 reaches 50°C, remove the camera and record the elapsed time.

Test 4.4 - Determine The Effect of Using a Double-Glass Dome

Remove the glass dome covering the camera lens and mirror. Install the dual glass dome over the lens and mirror. The equipment configuration is shown in Figure A-10.

1. Turn on all heaters and set the control circuits for a temperature of 800°F. Maintain this temperature for a period of 7 hours before proceeding.
2. Install the camera in the mock-up and move it to a position where the temperature is 400°F.
3. Monitor the temperature of the camera every 3-5 minutes starting at time zero ($t = 0$). Record the temperature on the video recorder
4. Record the following temperatures:

T1 = Camera Temperature read at the camera control unit

T2 = Temperature of the gap between the camera and camera housing. Read at thermocouple readout position 15.

T3 = Temperature within the camera dome. Read at the thermocouple readout position 16.

T4 = Temperature in the mock-up where the camera is located.
5. When temperature T1 reaches 50°C, remove the camera and record the elapsed time.
6. Repeat steps 1 through 5 using the following modifications to the camera assembly:
 - A. Place a foil shield over the rear of the camera assembly extending approximately 0.5" (1.27 cm) over the side of the camera. Insert the camera with shield into the mock-up.
 - B. Remove the foil shield. Turn on the cooling gas and allow it to flow through the assembly for 5 minutes before inserting the camera into the mock-up. Allow the camera temperature (T1) to reach 60°C before removing the camera.

- C. Wrap metallic foil around the rear and sides of the camera assembly before inserting it into the mock-up. Allow the camera temperature (T1) to reach 60°C before removing the camera.
- D. Remove the foil from the camera assembly. Insert the camera into the mock-up and allow temperature T1 to reach 71°C before removing the camera assembly. Record the elapsed time.
- E. Replace the foil around the camera and repeat step D above.

Figure A-10. Location of Camera Temperature Sensors

Section 5 - Determine the Effect of Exceeding the Camera's Maximum Rating

These tests will show the results on the image quality, if the maximum temperature of the camera is exceeded. The equipment configuration is the same as that used in Section 4.

Test 5.1 - Evaluate the Result of Exceeding Temperature Ratings

1. Turn on all heaters and set the control circuits for a temperature of 800°F. Maintain the temperature for a period of 7 hours before proceeding.
2. Install the camera into the mock-up and move it to a position where the temperature is 400°F.
3. Move the camera to a position where the smallest sample (1.0 mil wire) is visible. Change the Focus and Mirror controls to verify that they operate correctly.
4. Monitor and record the image quality, camera temperature (T1), dome temperature (T3), and the mock-up temperature (T4), every five minutes. Use the Focus and Mirror controls to verify proper operation of those functions every ten minutes.
5. Continue until the camera temperature (T1) reaches 90°C, remove the camera, and record the elapsed time.

Test 5.2 - Determine "Destruct" Temperature of the Camera

1. Turn on all heaters and allow the mock-up temperature to reach 420°C before inserting the camera.
2. Repeat Steps 3 and 4 of Test 5.1. Continue until the image deteriorates or disappears.
3. Immediately remove the camera from the mock-up and applied cooling gas, and record the elapsed time and temperatures T1, T3, and T4.
4. After five minutes of cooling, check for proper operation of the camera and its controls.
5. Repeat steps 1 through 4 to determine any cumulative effects.

EQUIPMENT USED

Description	Manufacturer: Model Number
Video Cassette Recorder (VCR)	Panasonic: AG-1820
Video Monitor	Panasonic: CT-2010-Y
Time, Date Generator	Mitsubishi: TDG-10U
Video Typewriter	FORA: VTW220
Camera & Control Unit	Videospection: 881
Camera Lighting Unit	Nuclear Systems Associates: N/A
Video Copy Processor	Mitsubishi: P61U