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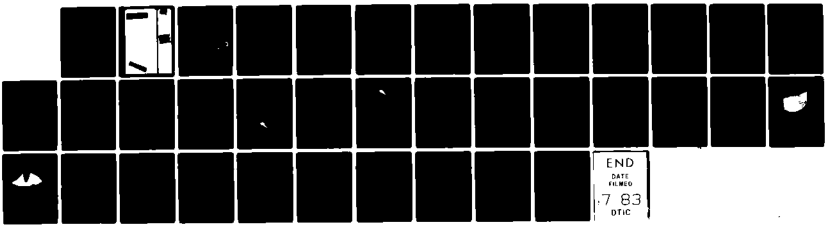

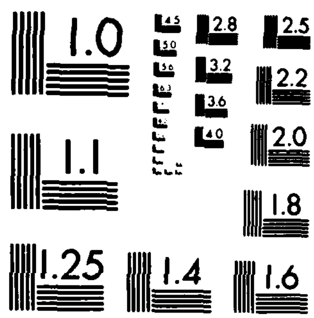

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Laboratory measurements have been performed on a test piece of a sonar dome rubber window (SDRW) which demonstrate the feasibility of using the collimated photon scattering (CPS) technique to detect and measure defects, especially voids, in SDRW.

The CPS technique was originally identified by IRT as a powerful industrial inspection method for certain nondestructive evaluation tasks about eight years ago and has since been successfully implemented by IRT in industrial inspection machines.

This research effort has demonstrated that CPS can distinguish between air and water filled voids in addition to detecting their presence, precise location and size. Computer programs previously developed by IRT were applied to the SDRW data for analysis and data display in two and three-dimensional plots which clearly show presence, location, size, and air or water filled status of voids.

A conceptual design is presented which demonstrates that CPS can be readily implemented in terms of practical, operational inspection hardware suitable for the in-dock inspection of domes installed in ships and for newly manufactured domes on a hydrotest fixture. Basic design parameters have been estimated and a scenario is proposed for a two-phase program for the design and construction of fieldable, operational hardware in about 27 months at an estimated total budgetary price of about $1.3 million. This schedule could be significantly shortened with the acceptance of some program concurrency and at some increase in price. Operational hardware could be engineered to be suited for operation by Navy personnel, or by IRT personnel on a service basis if that approach were selected.

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INSPECTION OF SONAR DOME RUBBER WINDOWS USING COLLIMATED PHOTON SCATTERING

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EXECUTIVE SUMMARY

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1. INTRODUCTION

As a result of the method currently used to manufacture Sonar Dome Rubber Windows (SDRWs), critical voids are often created in the rubber matrix, generally in the splice region. These may be the cause, or at least a precursor, of a number of failures which have occurred in domes while in service. The failure mechanism which results in ruptures of the dome may involve intrusion of salt water inside the rubber matrix with subsequent corrosion and weakening of the steel ply wires. These voids are usually wedge-shaped and may be continuous channels running the partial or full length of the splice providing a path for sea water to propagate through the matrix. There may be as many as four such voids, two at each splice edge. The average wedge dimensions are 0.1 inch (0.254 cm) by 0.25 inch (0.635 cm), the length of the void can be as much as 112 inches (2.845 m).

Because of the large size of the dome and accessibility only from the outside when installed, the SDRW presents a formidable problem for conventional nondestructive testing (NDT) methods. X-radiography, ultrasonic, and laser interferometry have been applied to date to detect voids. These methods have not yet demonstrated satisfactorily that they can locate voids in the rubber matrix and measure their size. Collimated photon scattering (CPS), or Compton scattering, methods developed by IRT Corporation offer the capability of three-dimensional imaging of voids and other flaws such as inclusions and porosity by point-to-point determination of density differences throughout the volume of a sample. The work discussed in this report demonstrates specifically the feasibility of using CPS to detect and measure voids in SDRWs. This effort has been funded by the Naval Research Laboratory which has been tasked by NAVSEA 63J to determine the most appropriate NDT method(s) to detect critical flaws in domes.

The most widely used X-ray or gamma-ray NDT and medical techniques are based on transmission measurements. Such applications range from simple radioisotope gamma gauging to complex radiographic imaging and computed tomography. All of them require access to two sides of the sample. With the exception of tomography, they offer no depth discrimination. They are generally not sensitive to small flaws in thick or dense samples, or samples enclosed in heavy wall containers because the response is averaged over the entire path of the beam through the sample. Therefore, if a void is oriented relative to the beam in such a way that the void volume intercepted is a small fraction of the total sample volume in the beam, the bulk density of the material within this volume and the transmission signal will not be affected enough by the presence of the void to produce sufficient contrast for reliable flaw detection.

In the CPS inspection technique, a narrow beam of X rays or gamma rays is directed into the sample to be inspected. A short segment of the incident beam within the sample is viewed through a multihole, focusing collimator aligned at an angle to the incident beam. The signal from a photon detector located behind this collimator consists of photons which are scattered from a small spatial region with the sample. This is the inspection volume whose size is defined by the intersection of the photon source beam and the focusing view of the detector collimator. The relevant features of the technique are shown in Figure 1. The inspection volume is scanned across the entire volume of the sample. The Compton scattering photon signal is measured at discrete points along the scan to generate a three-dimensional image of the electron or mass density of the material within the sample. This is accomplished either by moving the sample relative to the source and detector, or by moving the source and detector relative to a stationary sample. The sensitivity of the inspection is primarily determined by the ratio of the defect volume in the beam to the inspection volume. Since the inspection volume can be made very small by designing the source and detector collimator appropriately, high resolution and sensitivity to small voids or other flaws is achieved.

The scattering intensity data can be displayed in a variety of ways (in one, two, or three dimensions) depending on the application. Since the Compton scattered photon intensity is directly proportional to the mass density of the material within the inspection volume at each measurement point, any perturbations in the material density such as voids, porosity, and inclusions shows clearly in the scattering signal with high contrast regardless of attenuation of the incident and scattered beams by the sample. The equipment is designed so that the smallest defect to be detected generates a signal at a cluster of several inspection points. Furthermore, since the detector is located at an angle to the source beam, the inspection system can be designed so that access to only one side of the sample is required.

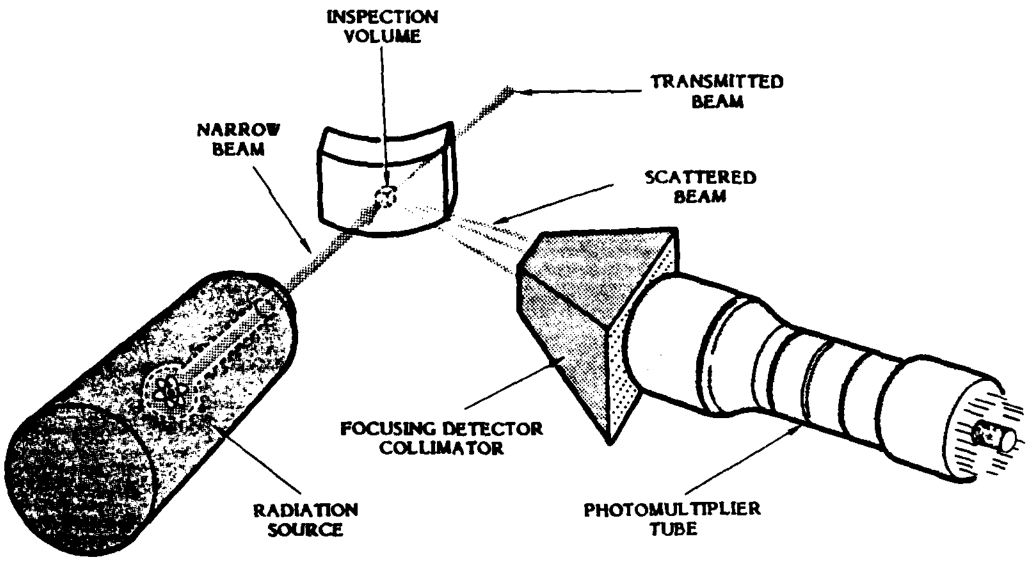

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Figure 1. Collimated photon scattering arrangement for detection and location of density anomalies in a material

The present work comprises a feasibility demonstration of the applicability of CPS for inspection of SDRWs. Under current funding, measurements were conducted on a sample panel of dome material to demonstrate that air filled voids as manufactured can be located and measured. Subsequently, the sample was filled with water and remeasured to show the difference in contrast between the response to air filled and water filled voids. Since installed SDRWs are practically accessible only from the outside, the photon source and detector were located on the same side of the sample panel. The appropriate data display mode was selected to show clearly the location and shape of the voids found. Additionally, the following were addressed:

1. Benefits and limitations of resolution required to distinguish air filled from water filled voids.
2. Benefits of computerized data and image reconstruction.
3. Design parameters of a prototype SDRW inspection system based on results of the feasibility demonstration measurements.

4. Prototype system source intensity and data acquisition requirements.

5. Time and cost estimates for development of a prototype inspection system.

Since a radiation source will be used in the inspection system, radiation safety was also addressed.

In accordance with the Scope of Work, an existing IRT laboratory CPS test facility was modified and CPS measurements were performed on a sample panel of dome material supplied by NRL. The experimental setup, measurements performed, and data generated are discussed in Section 2, which follows. Based on results of the measurements and information obtained in visits to the Long Beach Naval Shipyard and the B. F. Goodrich plant at Akron, Ohio, a conceptual design was developed for a prototype inspection system. The conceptual design, estimated parameters and inspection times are discussed in Section 3. Conclusions drawn from the present wc and recommendations for continuation of the development effort are presented Section 4.

2. FEASIBILITY DEMONSTRATION

Feasibility demonstration measurements were performed on a section of sonar dome panel supplied by NRL. This sample is described below. The experimental setup consisted of the modified IRT Compton scattering test facility and peripheral equipment and instrumentation all available from company owned equipment inventory. The CPS data were stored on floppy disk and transferred to the IRT central computing system for plotting using existing software.

2.1 LABORATORY SETUP

A schematic diagram of the experimental setup used for the measurements is presented in Figure 2. It shows the approximate orientation of the sample panel relative to the photon source and detector. The source consists of Cobalt-60 (about 250 Curies) in a spherical-lead shield. Additional biological shielding is provided by lead bricks surrounding the spherical shield. A beam is extracted through the main source collimator which is designed so that the cross section of the beam at the position of the inspection volume is about 0.125-inch (0.3175-cm) square. The sample is positioned on a pedestal which is mounted on a rotating table. The vertical position of the sample can be changed manually. The rotating table is attached to translation tables which move the sample in the horizontal plane of the source and scattered beam. The translations are normal and parallel to the direction of the source beam. A NaI(Tl) detector 3 inches (7.62 cm) in diameter by 3-inches (7.62-cm) long was used behind a focusing collimator designed so that the dimension of the inspection volume in the direction of the source beam was 0.125 inch (0.3175 cm). Therefore, the inspection volume for the present measurements was approximately a cube 0.125 inch (0.3175 cm) on each side. The data acquisition and control system is described below.

2.2 SAMPLE

The sample used was cut from a 15-inch (38.1-cm) long and approximately 2-inch (5.08-cm) high panel labeled CN5 supplied by NRL. Its thickness varied from about

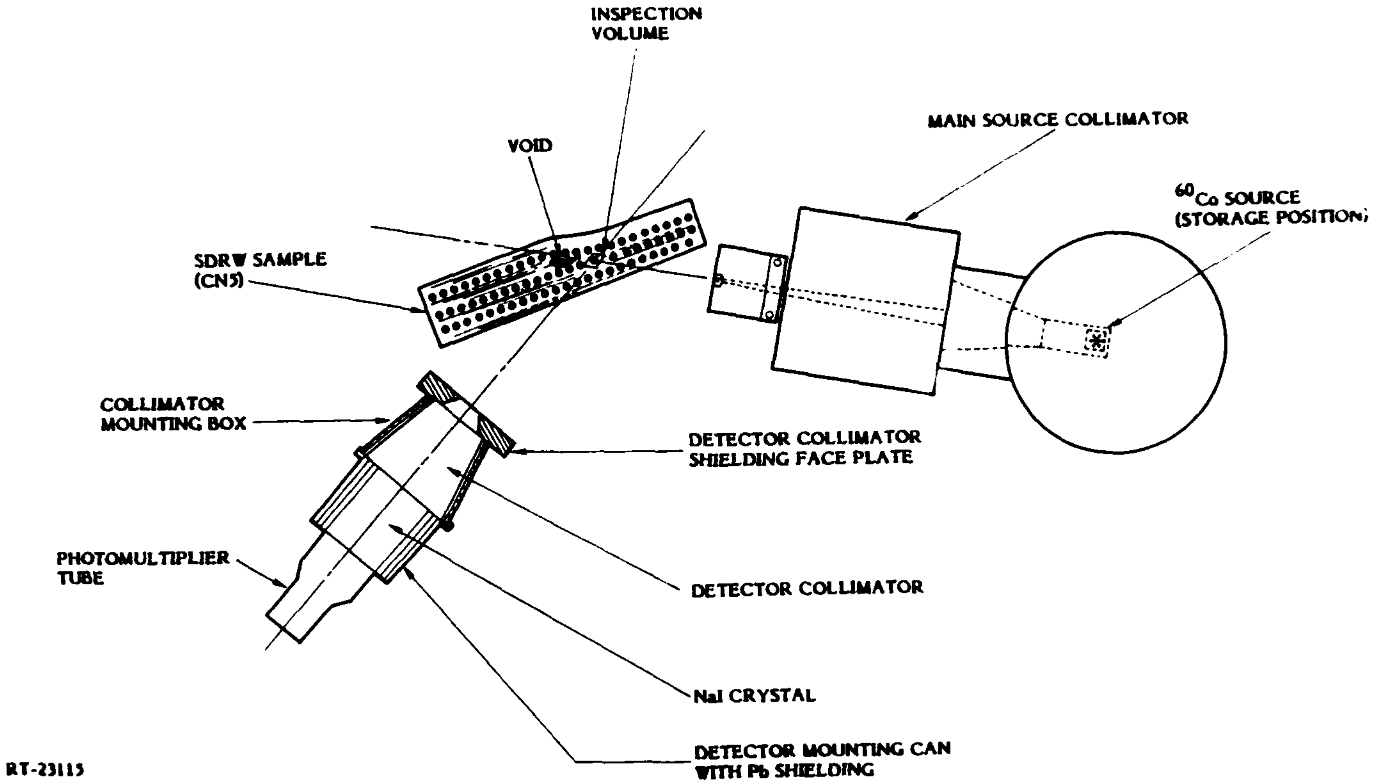

Figure 2. The experimental CPS setup used. The source, sample and detector configuration are shown.

1 inch (2.54 cm) to 1.375 inches (3.4925 cm). The part that was cut for use in the measurements is shown schematically in Figure 3. It is 6.25-inches (15.875-cm) long and varies in thickness from about 1 inch (2.54 cm) to 1.25 inches (3.175 cm). A single void is visible running through the height of the sample at about the center of the horizontal cross section. The void is shaped approximately as shown in Figure 3. Its maximum width is about 0.125 inch (0.3175 cm) and narrows abruptly after about 0.125 inch (0.3175 cm).

The rectangular parallelopiped outlined inside the sample is 1 inch (2.54 cm) by 2 inches (5.08 cm) by 2 inches (5.08 cm). It represents the volume of the sample in which measurements were performed. These are discussed in a later paragraph. The rectangle midway between the top and bottom of the sample is the horizontal plane for which data are presented below.

Two sets of measurements were performed on this sample. The initial measurements were made with the sample dry (air filled void). Subsequently, the bottom and two small vertical faces of the panel were sealed with silicone rubber thinned with acetone. The void was filled with water to simulate this case for an in-service SDRW. A second set of data was generated for the water filled sample.

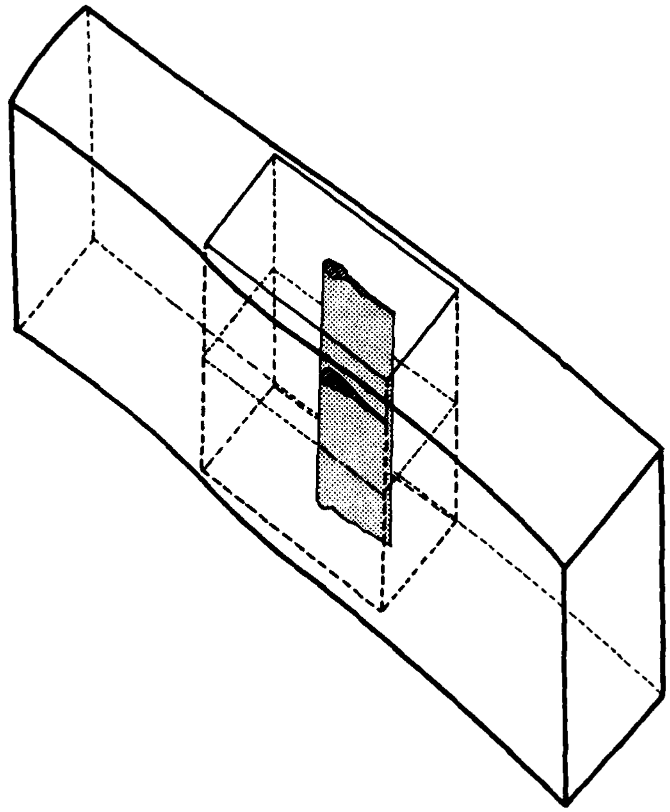

Figure 3. Schematic drawing of the sample panel used for the present measurements. It is 6.25 inches (15.875-cm) long, 2-inches (5.08-cm) high, and from 1 to 1.25-inches (2.54 to 3.175-cm) thick. The void runs through the height at the center of the sample. Measurements were performed in the volume outlined at the center of the sample.

2.3 DATA ACQUISITION AND CONTROL SYSTEM

Pulses from the detector corresponding to scattered photons are amplified, digitized, and counted by the appropriate electronics. The counting system is interfaced to a PDP-11 computer. The rotating and translating table motors are controlled by a positioning motor controller which is also interfaced to the computer. The operating software allows selection of the counting period, indexing of the inspection volume position, and the limits of translation normal and parallel to the source beam, i.e., the extent of the scan. The observed count rates at each measurement point are stored on floppy disk together with the coordinates of the location of the inspection volume relative to the sample. Hard copy output of the same information is generated simultaneously by a printer.

2.4 MEASUREMENTS

All measurements were made within the sample volume outlined in Figure 3. Data were generated in sets corresponding to scans of horizontal planes at various elevations. The position of the planar scan was set manually starting at 0.125 inch (0.3175 cm) from the bottom of the sample panel. It was changed in steps of 0.125 inch (0.3175 cm) to a point 1.875 inches (4.7625 cm) from the bottom. This was accomplished by locating the sample at preselected points in the vertical direction relative to the plane defined by the source and scattered photon beams. Planar scans at each sample elevation were performed automatically on a 0.0625-inch (0.1588-cm) square grid. On a coordinate system with axes parallel to the sides of the rectangle in which the scan was done, and with the origin at a corner of the rectangle, each scan started at (0.125 inch, 0.125 inch). The sample was then translated so that the inspection volume center was incrementally moved 0.75 inch (1.905 cm) in steps of 0.0625 inch (0.1588 cm) in the direction normal to the surface of the panel corresponding to the outside of the dome. Next, the inspection volume position was moved 0.0625 inch (0.1588 cm) in the direction along the length of the sample and incremented as before along the width. This was repeated through a translation range covering 1.75 inches (4.445 cm) along the length of the sample. A background measurement was made at the end of each linear scan along the width of the sample by automatically moving the inspection volume outside the sample. This background was used to correct the data generated in the corresponding linear scan.

Similar measurements were made with the sample panel dry (air filled void) and with the void filled with water. The latter consisted of planar scans limited in extent to the immediate vicinity of the void. They generally covered a region 0.4375-inch (1.1112-cm) wide by 1.0625-inches (2.6988-cm) long.

2.5 EVALUATION OF RESULTS

All of the data generated in the present measurements were stored on floppy disk. They were later transferred to the IRT central computer for analysis, and existing plotting routines were used to produce two-dimensional plots of the observed scattering intensities. Such plots were generated for each planar scan made with the sample in the dry and water filled conditions. All of the plots exhibited lower scattering photon intensity at points where the inspection volume intercepted the void. This is the typical CPS response which shows a decrease in signal when the inspection volume is partly filled with either air or water. When a flaw is scanned, the average mass and electron density of the material within the inspection volume is lower than it is when it is totally occupied with ply material.

The plot of the intensities observed in scanning the plane midway between the top and bottom of the sample SDRW panel (Figure 3) is presented in Figure 4. This is typical of the plots generated for each of the scans made in the sample with the air filled void. The orientation of the plot is indicated relative to the inside and outside surfaces of the dome. Three regions are distinguished by different levels of scattered photon intensities. They are the fill-rubber layers on both sides of the ply region and the ply region itself. The two fill-rubber layers are lower density regions, and therefore are distinguished by lower scattered photon intensities. The plies contain both rubber and steel wire. Since the inspection volume is relatively large, it is never totally occupied by either steel wire or rubber in this region. Rather, at each point is its filled partly with rubber and partly with steel resulting in an effectively higher density region. Individual wires can be resolved by designing the collimation so the inspection volume is sufficiently small. This would result in slower inspection times and is not required to detect critical flaws.

The void manifests itself as the lower scattered photon intensity area in the ply region at about the center of the plot. The area of the void consists of the lowest intensities in the region corresponding to the widest part of the void as shown in Figure 3. The difference in intensity between the void area and the nearby ply region, i.e., contrast, is lower where the void is narrow as shown in Figure 3. However, even this area of the void is clearly visible in the data.

Figure 4 is a map of the observed, raw data. Alternatively, the data can be processed by smoothing, subtracting the background, compensating for sample self-shielding (discussed below), and thresholding (normalization) to allow selection and clustering of only those points within the void. This can all be accomplished by software in an automatic defect recognition mode. In addition to highlighting the void by displaying and/or color coding only the points in the void, this method would allow automatic determination of void dimensions. A mockup of such a display is presented in Figure 5 which shows the highlighted region superimposed on the same plot presented in Figure 4. The shaded, void area is derived by selecting those points where the scattered photon intensity is lower than a predetermined threshold value.

The corresponding data obtained by scanning the midplane of the sample with the water filled void are presented in Figure 6. This plot exhibits the same features discussed in connection with the scan of the air filled void shown in Figure 4. The

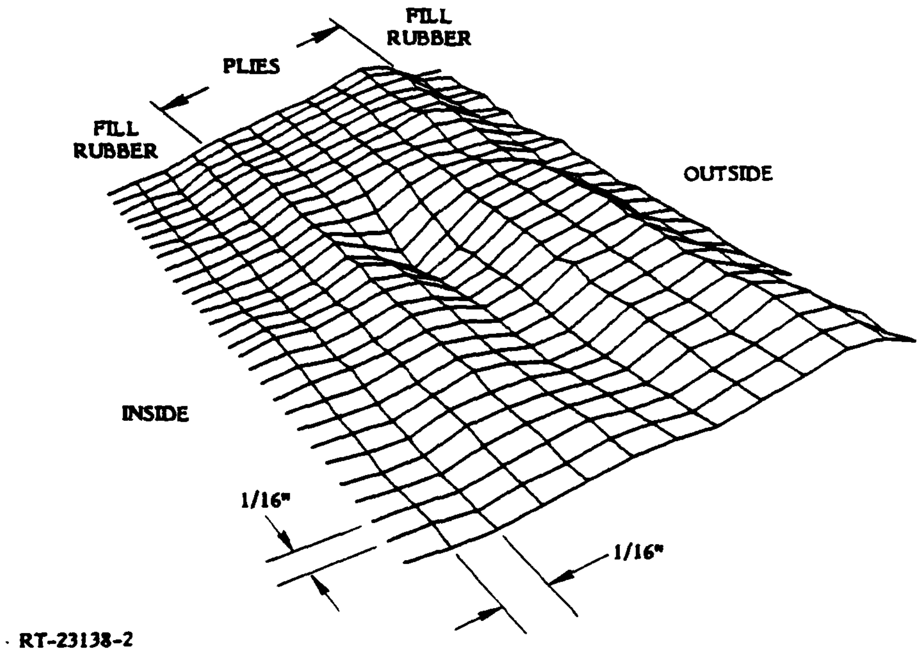

Figure 4. Plot of the scattered photon intensities observed in the scan of the midplane of the sample SDRW panel. The air filled void manifests itself as the lower intensity area in the middle of the ply region.

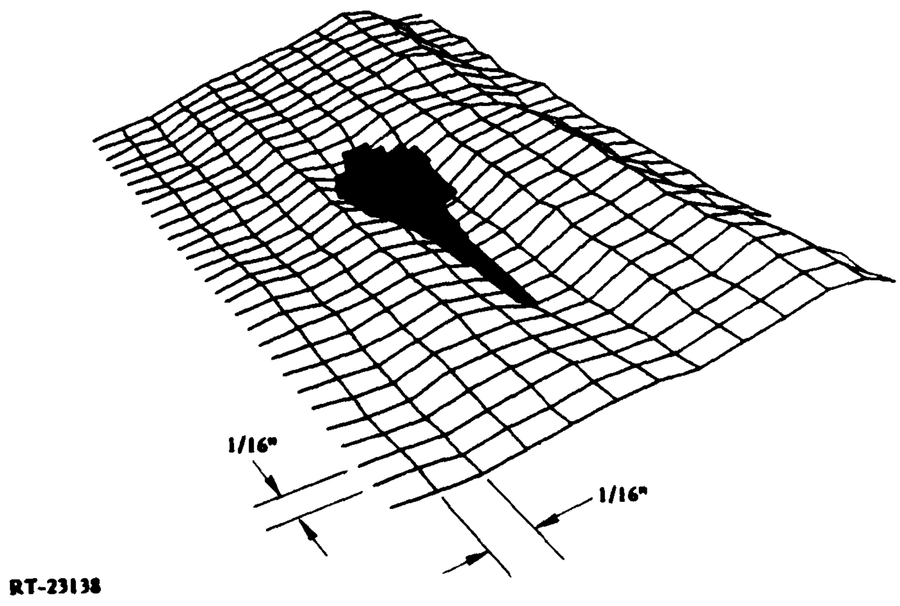

Figure 5. Plot of the scattered photon intensities observed in the scan of the midplane of the sample SDRW panel with air filled void. The superimposed dark area is a mockup of the processed defect area display.

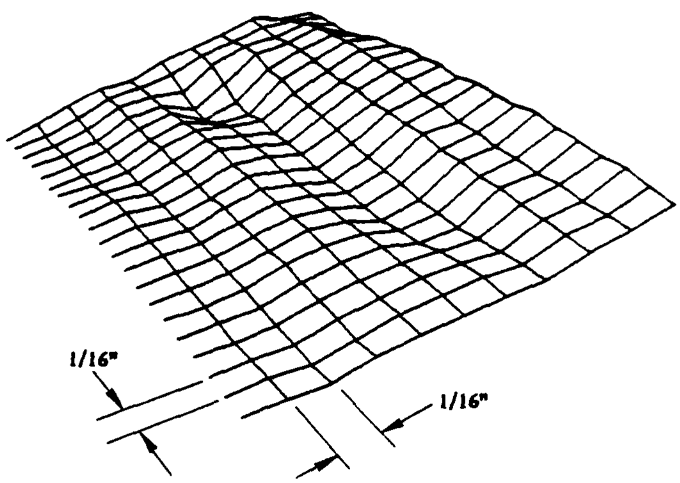

Figure 6. Plot of the scattered photon intensities observed in the scan of the midplane of the sample SDRW panel. The water filled void manifests itself as the lower intensity area in the middle of the ply region.

difference in contrast between the intensities in the void and the nearby ply areas for the air and water filled conditions is not readily apparent from a comparison of the corresponding plots (Figures 4 and 6). The difference is demonstrated below by comparing the cross sections of the corresponding planar scans through the widest part of the void for the two cases. For completeness, a mockup of the reduced data corresponding to the scan shown in Figure 6 is presented in Figure 7. The same comments made in connection to the information presented in Figure 5 for the case of the air filled void apply to the corresponding information shown in Figure 7 for the case of the water filled void.

A three-dimensional display of the void can be created by stacking the processed data corresponding to each of the planar scans performed at the different points along the length of the defect. This can be done entirely with software in such a way that the viewing angle is controlled by the operator and can be changed to allow detailed examination of the void. This is further enhanced by the capability to zoom in on specific regions for examination of the local structure.

Cross sections of the planar scans through the widest part of the void for the two cases presented are shown in Figure 8. These plots represent linear scans along the

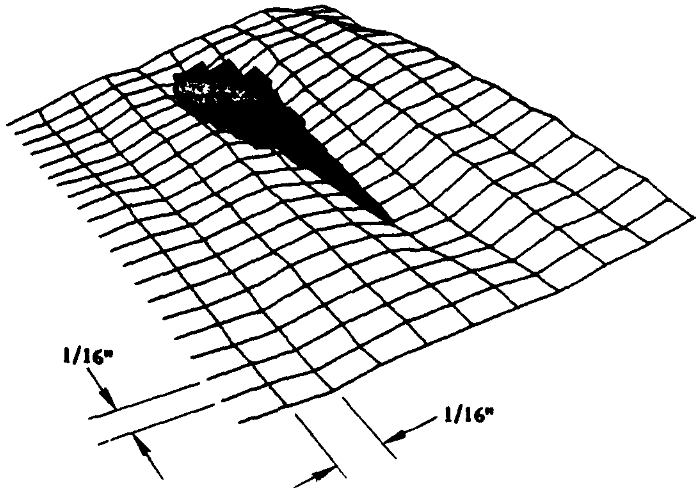

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Figure 7. Plot of the scattered photon intensities observed in the scan of the midplane of the sample SDRW panel with the water filled void. The superimposed dark area is a mockup of the processed defect area display.

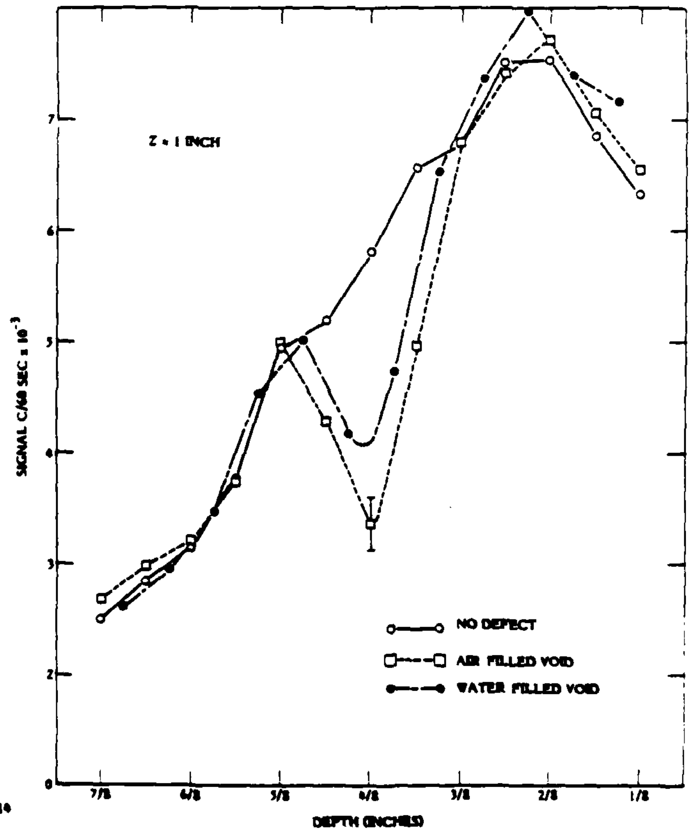

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Figure 8. Linear scans through the thickness of the sample SDRW panel at the widest part of the void for the air filled and water filled cases discussed in the text, and at a nearby region which does not contain a void.

thickness of the sample panel. The depth coordinate is measured from the outside surface of the dome. The three curves represent scans through a region with no void (open circles), through the water filled void (filled circles), and through the air filled void (squares). The structure is the same as discussed in connection with the corresponding planar scans presented above. The slope of the curve, increasing toward the outside surface of the dome, is more pronounced in this figure because of the vertical scale used. It is due to the shielding of the source beam incident on the inspection volume and of the scattered photons by the dome material. The deeper within the sample the inspection volume is located, the greater the shielding and the lower the observed signal, assuming a uniform sample. The effect of irregularities in the sample is superimposed on this normal response.

A comparison of the curves in Figure 8 shows the effect of the void on the observed CPS response. The decrease in the scattered photon intensity at the location of the void relative to the response observed in the absence of a defect provides clear evidence of the presence of the void whether it is filled with air (as manufactured) or with water. Furthermore, the decrease in the intensity in the void is smaller when the void is filled with water than that observed when it is filled with air. This difference in contrast for the two cases is as expected due to the higher density of water relative to air.

The absolute difference in contrast is more clearly displayed when the background and self-shielding effect of the sample material are removed. This is a data processing step which would be performed by the data analysis software in the automatic defect recognition mode. It was done manually for the data presented in Figure 8. The corrected intensities which now represent only the effect of the void are plotted in Figure 9. It is now readily apparent how thresholding can be performed on the data to identify only those points located within the void. They are the points with intensities at a certain level below the average intensity at points outside the void.

Although the above data clearly demonstrate that voids in SDRWs, whether they are filled with water or air, can indeed be detected by CPS methods, they are not sufficient to distinguish between the two fluids. This is due to the size of the inspection volume used in the measurements which is large relative to the dimensions of the void. The reason it was possible to discriminate between air and water in the present case is because the size of the void was known to be the same in both sets of measurements. The choice of the inspection volume size for these measurements was dictated by the requirement for the shortest inspection time possible while still allowing for unambiguous detection of the presence of voids and determination of their

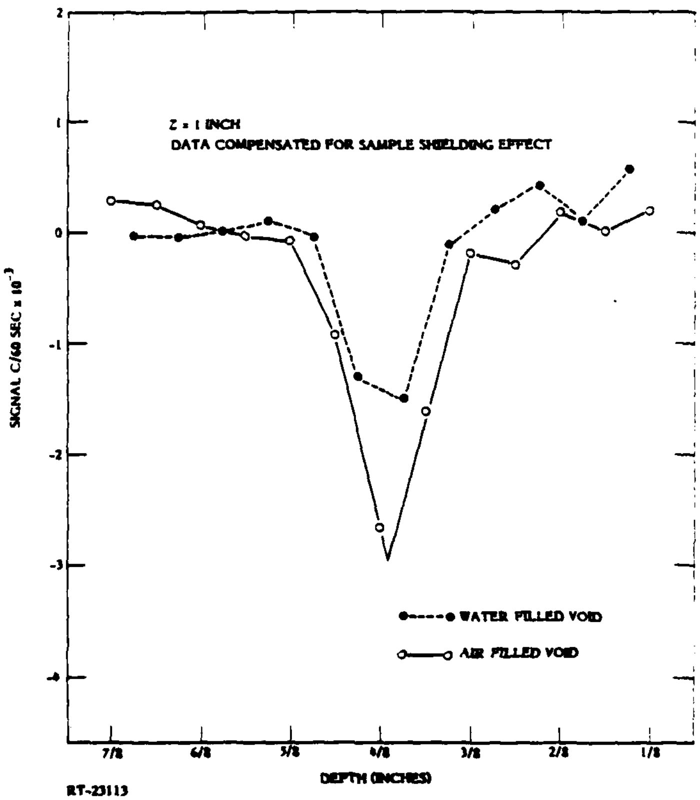

Figure 9. Linear scan data through the air filled and water filled void after compensation for background and sample shielding effects. The raw data are shown in Figure 8.

size. Once the latter is known, the content of the void in installed domes can be determined by use of narrower collimation which would reduce the size of the inspection volume sufficiently so that it can be located entirely within the void and occupied totally by the void fluid. This implies that the inspection of domes will require two steps. First, the voids will be quickly located and measured with a large inspection volume, and second, the content of the void will be determined by measurements with a small inspection volume at a relatively small number of points within the voids located previously.

3. CONCEPTUAL SYSTEM DESIGN

The conceptual design of the engineering prototype for an SDRW inspection system is described below. It is based partly on the laboratory measurements summarized previously, the information obtained during the visit to the drydock, and the information supplied by the manufacturer. It also draws upon the experience and judgement of cognizant IRT personnel regarding CPS inspection systems. It is anticipated that various aspects of the system will be modified on the basis of new information and/or input from NRL and NAVSEA.

This section describes various general design features of the proposed SDRW inspection system. It discusses the photon source and required intensity, detectors and source/detector configuration, mechanical handling system, data acquisition, processing and control equipment, and data analysis and display. The operational mode and operating conditions are discussed. The expected performance of the engineering prototype with regard to operation in the field consists of estimates based on current information. A scenario for the development of the system consisting of detailed design, fabrication and testing, and operation is discussed in Section 4.

3.1 OPERATIONAL MODE

Operation of the proposed inspection system will consist of two steps. First, the part of the dome to be inspected will be scanned rapidly to detect the presence of voids and measure their size. A relatively large inspection volume will be used for this purpose to minimize the inspection time. Its dimensions will be as large as possible, but consistent with the minimum dimensions of the voids. Having located the void(s) accurately relative to a fixed reference point, and determined the size, another set of collimators will be used to determine whether the void(s) are filled with air or water. The dimensions of the second inspection volume will be such that it can fit entirely within the smallest void to be detected. Only a small number of measurements will be required at various points within the void(s). Inspection time estimates are discussed later in this section.

3.2 PHOTON SOURCE AND DETECTOR CONFIGURATION

Application of the source and detector used in the present measurements for the inspection of the sonar dome is shown schematically in Figure 10. Both the source and the detector are located on the outside. In the prototype inspection system, the Cobalt-60 source will be replaced by a small linear accelerator-based photon source. The obvious advantage is the capability to turn this source off when not in use. There are two commercially available systems which may be used in the dome inspection system. One is the Varian Linatron 200A with a switchable 1 or 2 MeV electron beam. The other is the MINAC 3 which produces a 3.5 MeV electron beam. The Linatron is a more intense source, approximately 50 times as intense as the Cobalt-60 source used for the present measurements. The MINAC is physically smaller than the Linatron so that it can be located closer to the dome surface. The MINAC is also lighter which allows for easier handling. Since the MINAC is a newer product and less is known about it, all of the estimates generated with regard to the SDRW prototype inspection system have been based on the information available for the Linatron which has been in routine use around the world for about 20 years. It has been used primarily in medical applications, but it has more recently been applied to industrial inspection problems at the production level. IRT has used a Linatron in another CPS inspection system which is currently in operation.

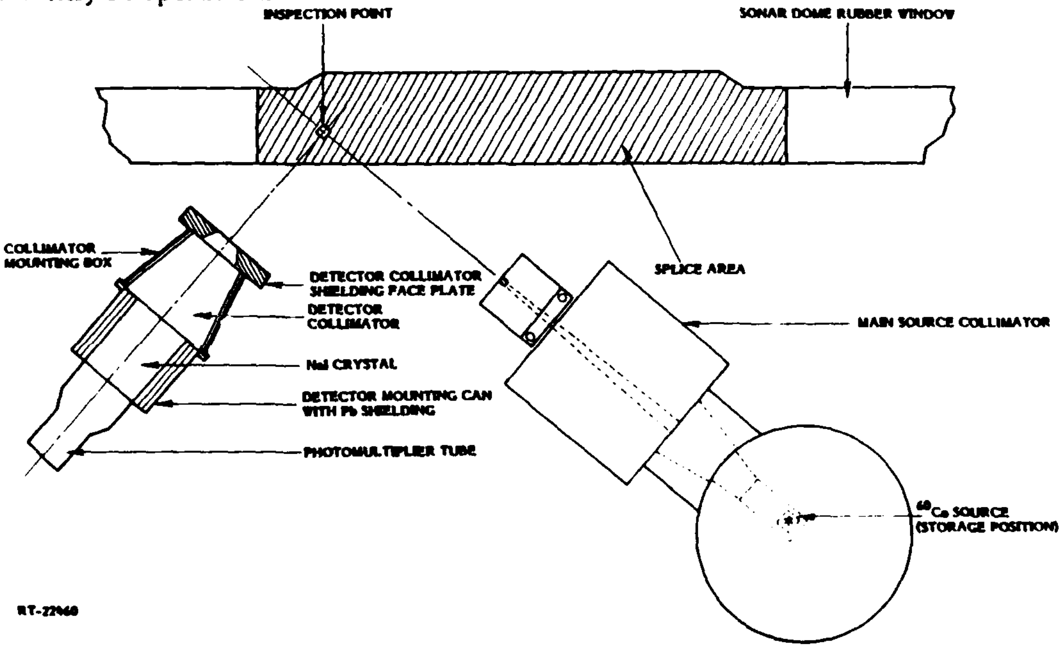

Figure 10. Schematic representation of the application of the source and detector system used in the present measurements for the inspection of the sonar dome. The source and detector are located on the outside.

The single 3-inch (7.62-cm) diameter by 3-inch (7.62-cm) long NaI(Tℓ) photon detector used for the present measurements will be replaced in the prototype system by a stack of four to six detectors 4-inches (10.16-cm) square by 4-inches (10.16-cm) long. The collimators will be designed so that the "large" inspection volume will be 0.125 inch by 0.125 inch (0.3175 cm by 0.3175 cm) in the horizontal plane, defined by the source and scattered photon beam, and 0.5 inch (1.27 cm) along the vertical direction. Another set of collimators will be designed so that the corresponding inspection volume will have dimensions in the range of 0.05 inch (0.127 cm) or less in the horizontal plane. The two sets of collimators will be remotely interchanged by the operator following detection and measurement of all the voids with the large inspection volume to determine the nature of the fluid within the void. The angle between the source and scattered beam will be between 90 and 130 degrees. The choice of this parameter will be dictated largely by the detailed curvature of the dome and the dimensions of the photon source.

3.3 MECHANICAL HANDLING SYSTEM

In the system currently envisioned, the photon source and detectors will move as a unit so that the inspection volume will scan the part of the SDRW where failures are likely to occur. That is the ply region in the splice area. To accomplish this, the mechanical handling system will be capable of translating the source and detectors in three mutually perpendicular directions. This is shown schematically in Figure 11. This figure presents a front view of an installed dome, the line of sight being along the centerline of the ship. The system will be designed to sense the inside surface of the dome and follow its contour through the ply region inspecting the layer of material approximately within one inch (2.54 cm) from the inside surface. Side and top views of the mechanical handling system concept with Linatron head and detector stack are shown in Figures 12 and 13, respectively. It may also be necessary to have the additional capability of rotating the source and detectors as a unit to preserve their orientation relative to the horizontal curvature of the dome.

3.4 OVERALL SYSTEM CONCEPT

A block diagram of the prototype SDRW inspection system is shown in Figure 14. The photon source, e.g., Linatron 200A or MINAC 3, with its associated heat exchanger,

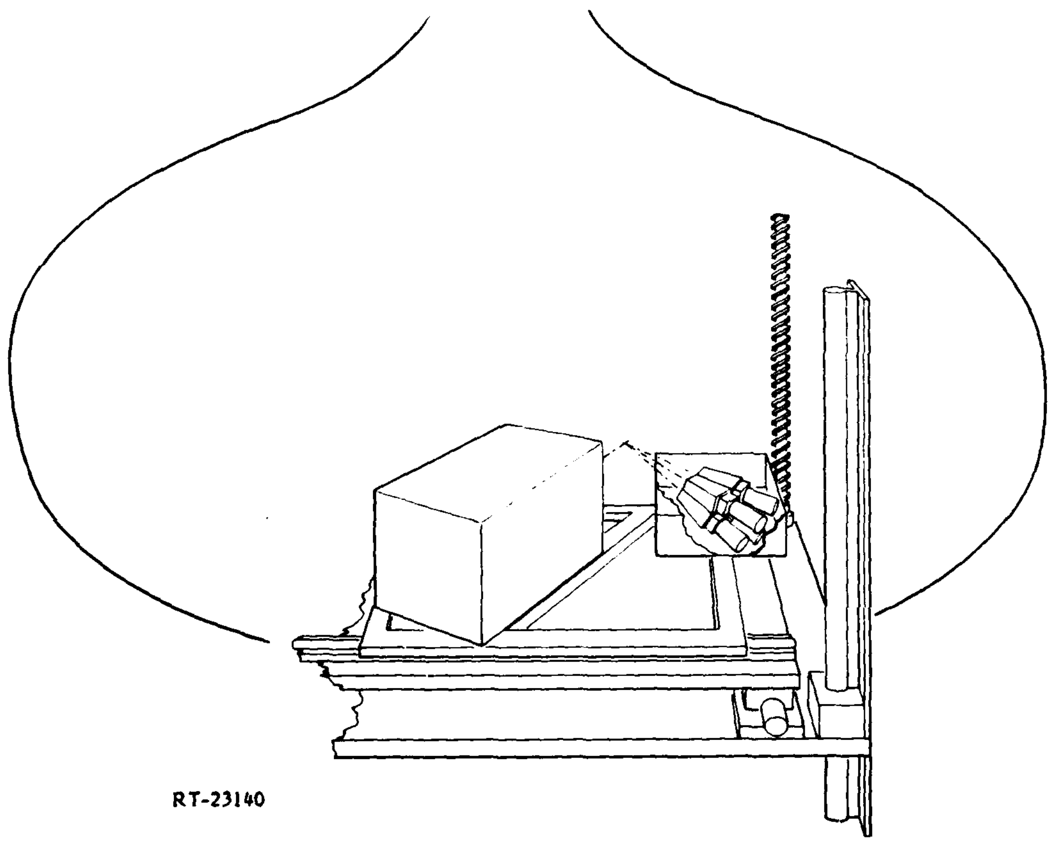

Figure 11. Conceptual representation of the mechanical handling system for the source and detectors of the prototype SDRW inspecton system

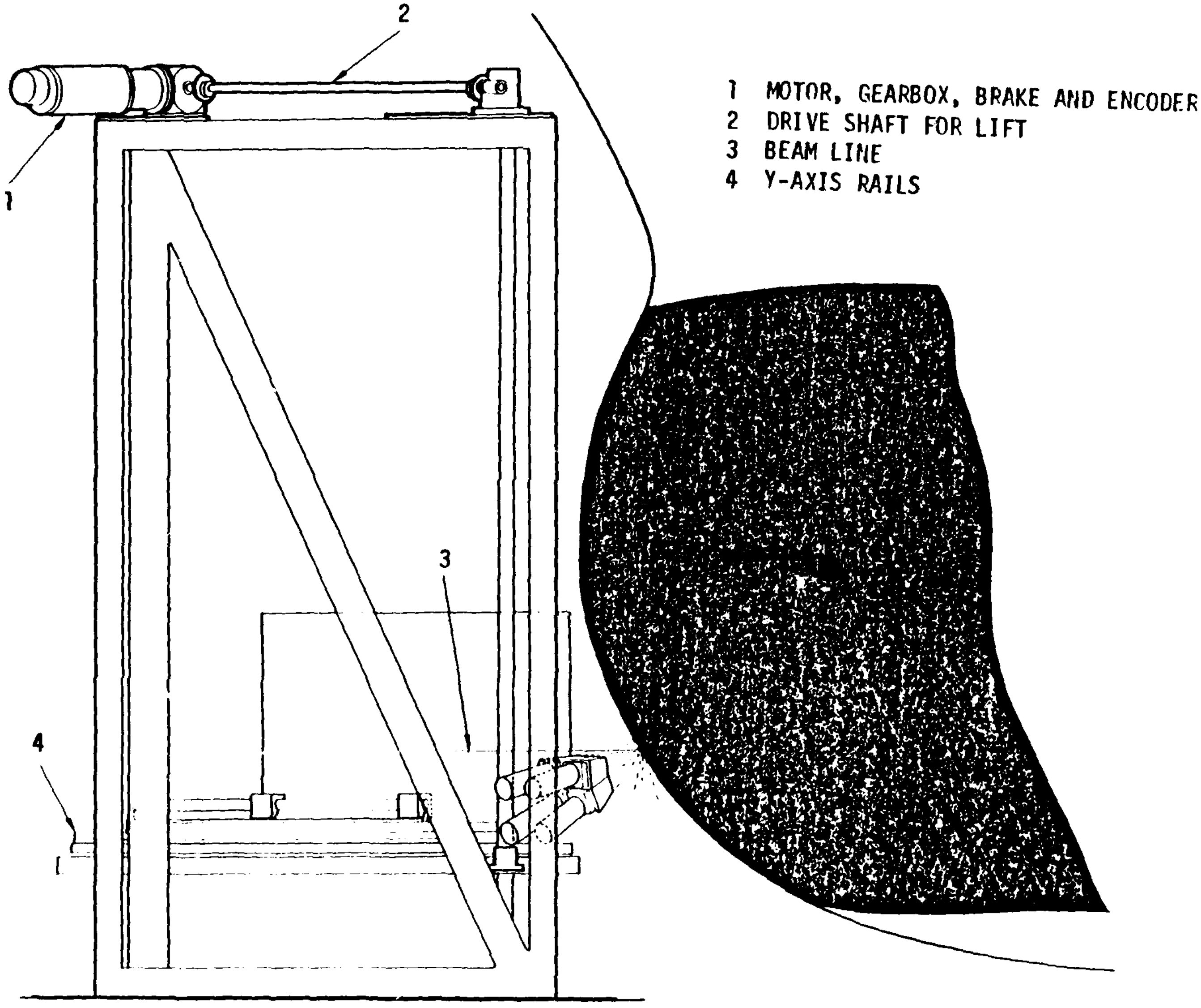

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Figure 12. Side view of the SDRW inspection system's mechanical handling component

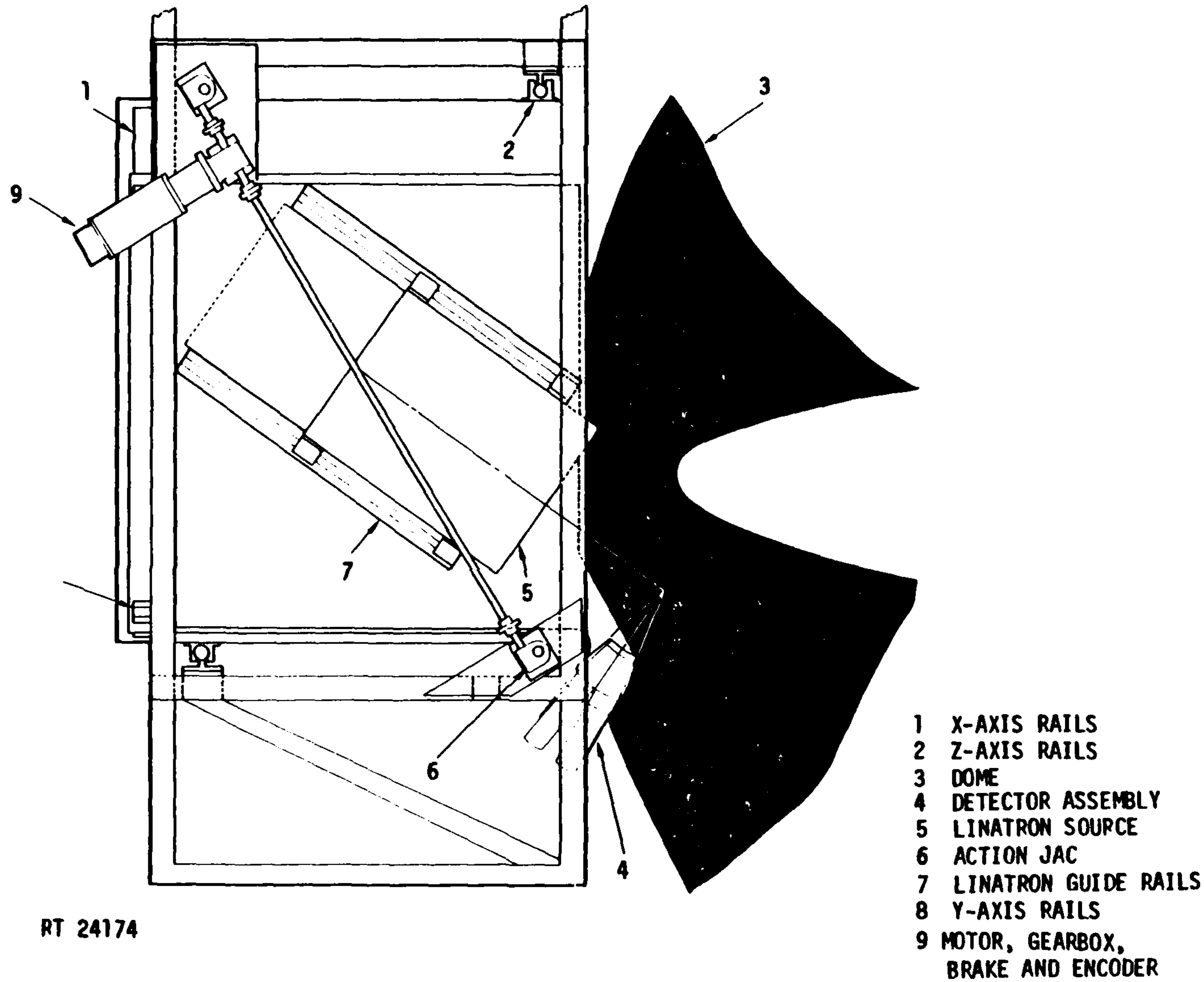

Figure 13. Top view of the SDRW inspection system's mechanical handling component

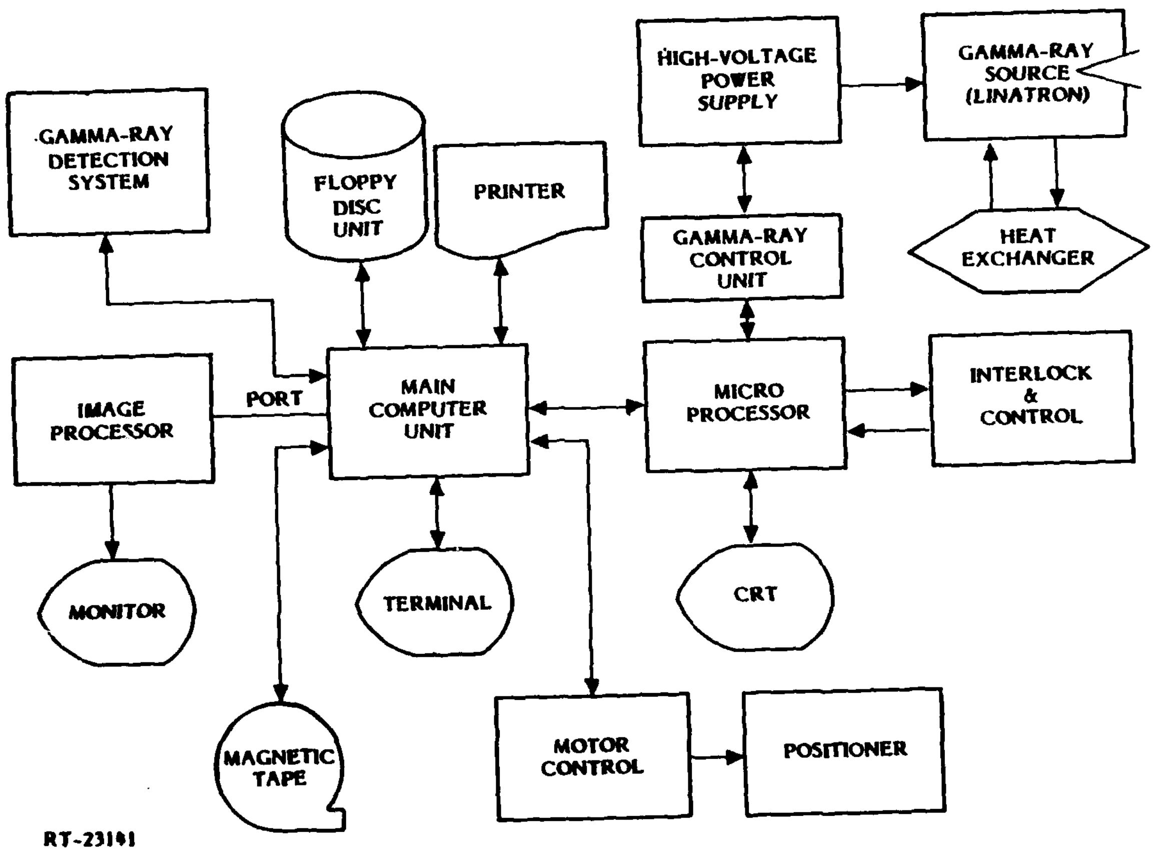

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Figure 14. Block diagram of the prototype SDRW inspection system

and high-voltage power supply are controlled and monitored by a microprocessor through the gamma-ray control unit. Status messages are displayed on the associated CRT monitor. The source control microprocessor is interfaced to a main computer which controls the overall system operation, data acquisition, processing, display and storage.

Positioning of the inspection head is performed by the main computer through the motor controllers of the mechanical handling system. The gamma-ray (photon) detection system consists of the photon detectors and associated high-voltage power supplies, signal conditioning, and signal counting electronics. The main computer unit turns the detection system on for predetermined periods of time and receives the scattering signal accumulated during the counting periods. The observed scattering intensities are correlated with positioning data and stored in memory. Hard copy output of inspection data and results, system status messages, input commands, scan identification and other information is generated by the printer. Raw data and inspection results will be stored on magnetic tape for recall, off-site analysis, and archiving.

CPS data will be processed by the main computer to correct for variations in the photon source output, background, and sample self-shielding. Data smoothing, thresholding, and clustering will be performed by the image processor and the processed image will be displayed on the associated monitor. Operator control of the system is maintained through the main computer terminal. The operating software is stored on floppy disk. It will be designed so that in the normal mode operation of the system will be fully automatic. However, the operator will be able to override the computer and operate the system in a manual mode, e.g., to scan selected regions of the dome or a standard to check the system and ensure proper operation.

The proposed SDRW inspection system will use a Linatron 200A as the photon source. The output of this device is about 50 times that of the Cobalt source used for the present measurements. The average photon energy is approximately 540 keV. The detector stack will consist of up to six NaI($T\ell$) detectors 4-inches (10.16-cm) square by 4-inches (10.16-cm) long. As indicated previously, two sets of collimators will be used which will be remotely interchangeable by the operator. They will be designed for two different inspection volumes. The first, to be used for rapid detection and measurement of voids present in the splice region will be 0.125-inch (0.3175-cm) square in the horizontal plane and 0.5-inch (2.27-cm) in the vertical direction. The second, to be used for determination of the type of fluid (air or water) within the void will have dimensions in the range of 0.05 inch (0.127 cm).

The scan using the large inspection volume will consist of measurements at discrete points throughout the SDRW region of interest. These points will be spaced 0.0625 inch (0.1588 cm) along the thickness of the dome, and 0.125 inch (0.3175 cm) in the direction normal to the centerline of the ship. In the vertical direction, the spacing will be as small as 0.5 inch (1.27 cm) for 100 percent inspection of the region of interest. The counting time per point will be about 0.05 sec for precision similar to that of the present measurements at the central part of the dome. On this basis, the total counting time for inspection of various sections of the dome in the splice region have been calculated and are presented in Table 1.

Table 1. Calculated Total Counting Times for CPS Inspection of a Number of Dome Sections Which Include All or Part of the Splice Region. (In a continuous scanning mode, these would be approximately equal to the total inspection time. A slice represents a planar scan defined in the text. The corresponding inspection volume dimensions are 0.125 inch x 0.125 inch x 0.50 inch.)*

Slice Spacing (Inches)	No. of Slices	Width of SDRW Section Scanned (Inches) 40	11 x 2	12	4 x 2
		Total Inspection Time (Hours)			
0.5	224	23.9	13.2	7.2	4.8
1.0	112	12.0	6.6	3.6	2.4
2.0	56	6.0	3.3	1.8	1.2
3.0	37	4.0	2.2	1.2	0.79
4.0	28	3.0	1.6	0.90	0.60
5.0	22	2.4	1.3	0.71	0.47
6.0	19	2.0	1.1	0.61	0.41
7.0	16	1.7	0.94	0.51	0.34
8.0	14	1.5	0.82	0.45	0.30
9.0	12	1.3	0.71	0.38	0.26
10.0	11	1.2	0.64	0.35	0.24

Inspection of SDRWs will be performed by scanning the region of interest in a manner similar to that used for the present measurements, i.e., by doing a number of planar scans (slices). The spacing of the planar scans along the arc of the dome in the vertical plane is given in the first column of Table 1. The corresponding number of slices to cover the full height of the dome are listed in the second column. The remaining four columns list the total counting time which will be required to scan the region of interest with the corresponding number and spacing of planar scans. Four different regions were considered in compiling the information in Table 1. They all have the same height, i.e., the height of the dome, but different width. The information in Column 3 corresponds to a region covering the part of the dome 20 inches (50.8 cm) on either side of the ship centerline. This is the area of the dome where all of the failures have occurred to date. Eighty-six point four percent of all failures have occurred in two 11-inch (27.94-cm) wide zones between 2 and 13 inches (5.08 and 33.02 cm) on either side of the ship centerline. The corresponding total counting times are given in Column 4. The last two columns correspond respectively to scans of a 12-inch (30.48-cm) wide section covering the entire splice and two 4-inch (10.16-cm) wide strips covering the two ends of the splice.

Excluding setup time, the total time which will be required to inspect a dome will consist of the counting time, time required to move the inspection head between measurement points, and, in the case of installed domes, time required for the additional measurements with the smaller inspection volume to determine the void fluid. The latter will depend on the number of voids detected and the number of measurements to be performed within each. The translation time could be a significant contributor to the total time required for inspection depending on the mode of operation. It will be minimal if the inspection head is translated continuously rather than incrementally during each planar scan. However, the resolution and contrast will be somewhat lower. Selection of the translation mode for the inspection head is an issue which must be addressed in the detailed design of the inspection system since it has a bearing on the design of the mechanical handling system. The calculated times presented in Table 1, however, indicate enough flexibility so that with the possible exception of the largest sample considered, i.e., 40-inches (101.6-cm) wide with 0.5-inch (1.27-cm) slice separation, total inspection times even lower than 24 hours should be feasible.

As indicated previously, processing of the scattering data will involve a number of steps. The observed intensities will first be corrected for variations in the photon output of the source due primarily to changes in the line voltage. The background contribution to the observed count rates may vary somewhat due to scattering of the transmitted beam by sonar instrumentation inside the dome. Therefore, the background will be monitored to compensate the data for any significant changes. The effect of shielding by the sample material on the measurements was demonstrated in Section 2. It must be removed prior to smoothing, thresholding and clustering operations. Data smoothing improves the statistical quality of the data and facilitates defect recognition and analysis through thresholding and clustering. Thresholding will be performed on the smoothed data to select the low-intensity points which will characterize the voids. The location and clustering of these points will be used to determine whether in fact a void has been found, its location, size and shape.

All data processing operations, defect recognition and analysis will be performed automatically by the main computer and image processor. The void parameters, e.g., location and dimensions, will be displayed on the image processor monitor together with the image of the defect. The system will be capable of two- and three-dimensional displays. Horizontal plane scans will be displayed as they are completed to show the cross section of the voids in the plane. Maximum dimensions and location coordinates will be displayed along with the defect. A three-dimensional representation of the voids found in the section of the SDRW scanned will be displayed inside an outline of the volume inspected. The detected voids will be color coded, and dimensional information such as length, maximum width and thickness will be presented together with location coordinates of selected points, e.g., endpoints. A mock-up of a three-dimensional image is shown in Figure 15. The operator will be able to manipulate the image to view the sample from various angles and zoom in at parts of the inspected volume of particular interest to examine the detailed structure of the defects.

3.5 OPERATING CONDITIONS

The inspection system will be transported to the shipyard or SDRW manufacturing plant in a dedicated truck or trailer. In the case of a shipyard, the truck with all the inspection equipment might be lowered by crane to the floor of the drydock. Alternatively, the mechanical handling system, the inspection head with the source power supply and heat exchanger, and the data acquisition, analysis, and control electronics mounted on a skid might be handled separately. The truck and inspection system components will be designed to facilitate the transfer and expedite setup of the equipment in preparation for the inspection.

The mechanical handling system will be positioned in front of the dome, it will be properly oriented and leveled. Next, the inspection head will be mounted on the handling system. The remaining equipment might be located at a distance of up to about 100 feet (30.48 meters) away. Electrical connections will be made and the system will be powered up. The photon source and associated equipment will operate from a 208 Y/120V, 50A 60 Hz circuit. Standard 115 V ac, 60 Hz lines will be required for the remaining equipment. Prior to commencing inspection of the dome, the system

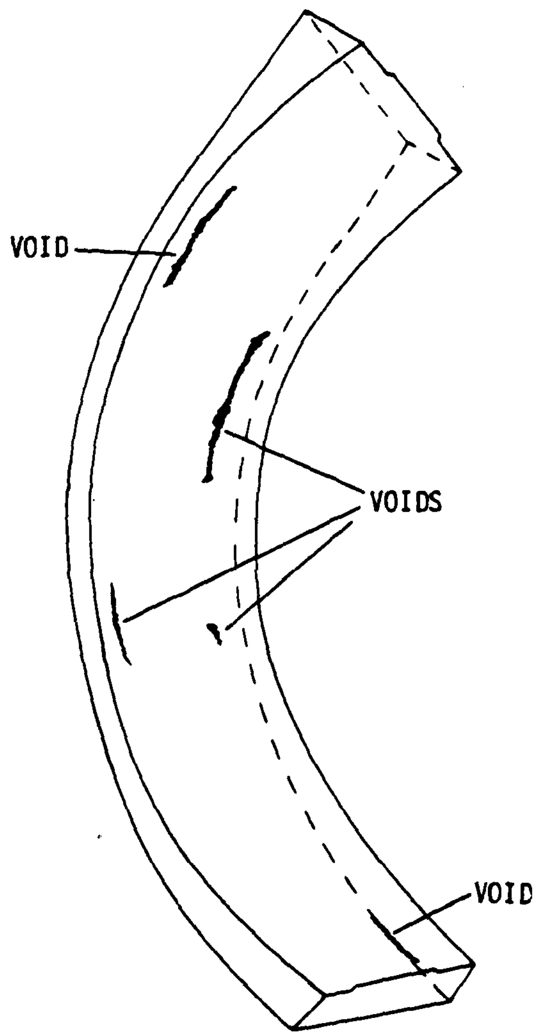

Figure 15. Mock-up of a three-dimensional display of voids within an outline of the volume inspected

will be checked using reference standards to ensure that every component is operating properly.

Operation of the inspection system will not preclude normal activities within the dock. At worst, it might restrict access to the immediate vicinity of the sonar. The setup procedure and operation of the system will be designed to minimize interference with other activities in the drydock. Since a radiation source is involved, the issue of radiation health physics will be properly addressed in the design phase. Operation safety procedures will be established and strictly followed to monitor radiation levels near the dome to ensure personnel safety. Any areas where radiation levels above the minimum allowable are detected will be roped off and clearly labeled to restrict access.

The photon source will be shielded by the manufacturer. Additional shielding will be added if necessary to ensure that radiation levels near the source are negligible. Since the source photon beam will be finely collimated, the radiation level will be very low in the immediate vicinity. This has been found to be the case in the various CPS applications at IRT. The operator is able to work near the beam without danger of exposure to significant radiation levels. The only high-level radiation area will be directly in the beam path. Access to this area will be prevented by an interlocking cover. The unscattered part of the source beam will emerge from the inside surface of the SDRW. Since the dome is filled with sonar equipment containing high-density material and since the material intercepts the transmitted beam throughout the scan, the source radiation which penetrates the dome should be totally absorbed by the sonar structure. This should be verified using detailed information on the sonar equipment to ensure that the transmitted beam will not pass through the sonar without being absorbed. If it is found that significant radiation emerges from the dome side opposite the source, provisions will be made to place shielding material, e.g., keel blocks, at the appropriate locations to absorb this radiation.

4. CONCLUSIONS AND RECOMMENDATIONS

Originally used in medicine, CPS methods are now being used or evaluated for application in several industrial NDT areas including military ordnance, rocket motors, jet engine components, and precision nuclear components. Industrial applications of CPS were pioneered by IRT eight years ago. In the process, the state of the art has been advanced significantly, extending the capability to inspect larger objects with smaller defects than was previously possible. A key development is the IRT high resolution, high throughput focusing collimator. This collimator makes possible the use of very small inspection volumes in high resolution measurements for detection of very small defects.

The measurements discussed in this report demonstrate that CPS methods can be applied to detect the presence of voids in the splice region of installed or newly manufactured SDRWs and measure their size. A relatively large inspection volume is used for this purpose. Its use also results in practical inspection times. A smaller inspection volume can be used in addition to differentiate between air filled and water filled voids in installed domes. Based on the present data, available SDRW design information, and commercial photon source specification, a CPS system can be developed and put into operation to inspect sonar domes for critical voids.

A scenario for the development of a prototype SDRW inspection system is presented in Table 2. A phased approach is suggested to maximize NRL/NAVSEA control of the project and minimize risk and associated higher costs. A cost reimbursement contract is envisioned. Phase I consists of the work described in this report. Phase II involves detailed mechanical and electrical design of the prototype system, detailed specification of software requirements, and specification of all purchased items. In Phase III, suppliers of the items to be purchased will be selected, equipment and materials will be purchased, parts will be fabricated, and the system will be assembled and tested. The prototype system will be used to inspect domes in Phase IV.

The costs for Phases II and III shown in Table 2 are budgetary estimates based on our current understanding of the NRL/NAVSEA requirements. They depend on the

Table 2. Suggested SDRW Inspection System Development Scenario. (Phase I has been completed. The budgetary price and time estimates were generated based on a system with the capabilities described in Section 3. It was also assumed that IRT will operate the system as a service to NAVSEA.)

	Phase	Estimate to Complete	
		Time (Months)	Cost ($1,000)
I.	Feasibility Demonstration and Conceptual Design	June 6, 1983	46.534 (Actual)
II.	Detailed Design	9	325
III.	Fabrication and Testing	18	980
IV.	System Operation	Continuous	TBD

desired system capabilities and on who will operate the system and how. In generating the current estimates, it was assumed that the system will have the capabilities described in Section 3 and that it will be operated by IRT under a service contract to NAVSEA. The times required to complete the corresponding tasks can be shortened significantly. However, the costs will be higher, and they will be reflected in higher prices. The time necessary to complete both Phases II and III may be reduced to 14 months. This assumes timely delivery of the photon source, delivery time for a Linatron is 10 months, and requires that Phase III be funded about a month after the start of Phase II and that the two phases be performed concurrently. More accurate time and price estimates can be generated for the follow-on phases in the development of the SDRW inspection prototype system. However, NRL/NAVSEA input is required to specify the desired system capabilities and mode of operation.

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