DESIGN AND CHARACTERIZATION OF THE NEUTRON RADIOGRAPHY BEAM PORTS AND NEUTRON RADIOSCOPY IMAGING SYSTEMS AT THE UNIVERSITY OF MICHIGAN PHOENIX MEMORIAL LABORATORY

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INTRODUCTION

Neutron Radiography and Neutron Radioscopy are rapidly becoming valuable tools for non-destructive testing and basic research with a wide variety of applications. The Phoenix Memorial Laboratory(PML) at the University of Michigan has developed a neutron radiography facility capable of both film neutron radiography and neutron radioscopy and has been using this facility to study several phenomena of interest to researchers in many areas.[1,2,3,4,5,6]. Neutron radiography is analogous to x-ray radiography in that a beam of radiation is modulated by an object and that modulated beam is used to form an image of the internal structure of the object. Neutrons can be used to image phenomena that x-rays are incapable of such as the presence, absence, or movement of hydrogenous materials inside metals such as aluminum or steel. This has led to the development of a neutron radiography facilities throughout the world to provide a means for imaging these phenomena.

In neutron radiography there are three basic methods used to obtain images using neutrons. These are 1) film neutron radiography, 2) neutron radioscopy, and 3) transfer neutron radiography. Figure 1 illustrates the basic differences of the first two methods. In film neutron radiography, the attenuated neutron beam is converted into a secondary form of radiation(such as electrons, gammas, or visible light) which is used to expose the film. The film is then developed similar to film used in x-ray radiography. This method is most useful for static, non-changing, phenomena where high resolution is required. If the phenomena or object of interest is moving or changing with time, the second method, neutron radioscopy, can be used. In neutron radioscopy, the modulated neutron beam is converted into a light image, electronically intensified, and viewed by a TV camera. This video image is then often input into a computerized image processing system for image enhancement or data collection.

FACILITY BEAM PORTS

The neutron radiography facility at PML is located in the Ford Nuclear Reactor facility on the North Campus of the University of Michigan. The thermal neutron source is a two Megawatt MTR type reactor reflected on one side with deuterium oxide. Figure 2 is a horizontal cross section showing the reactor core, the deuterium oxide tank, and the major horizontal beamports.

There are currently two beam ports available for neutron radiography. The first port is the horizontal "E" port shown in Figure 2. Figure 3 is a more detailed representation of "E" port showing the main spatial relationships. The beam exits the D_2O tank in an evacuated 12.7 cm. aluminum tube. The front 122 cm. of this tube can be flooded with water to work on the beam shutter. A 12.7 cm. lead plug is installed near where the aluminum tube penetrates the pool containment wall to reduce the gamma content of the neutron beam. Figure 3 shows two different imaging planes, one for neutron radioscopy imaging and one for film imaging. Figure 4 shows the construction materials used for shielding the horizontal neutron radiographic facility. Most of the walls are constructed of high density concrete blocks(50% iron ore by weight) with three large shielding panels made of benelex, borated polyethylene, and lead that can be moved with a fork truck to allow access for large items such as engines or transmissions. This horizontal beam port has a beam with a L/D of 55.2(at the neutron radioscopy imaging plane) and a L/D of 62.4 at the film imaging plane. The beam diameter at the neutron radioscopy imaging plane is 30.5 centimeters. This beam has a thermal flux of 3.2×10^6 neutrons/cm^2 sec. with a gamma content of 1.1 R/hr and a cadmium ratio of 47. This beam port is used for large objects and small objects where high resolution is not necessary. A high resolution horizontal beam port is currently being designed with a variable L/D from 200 to 400 and a variable field size from 10 cm. to 36 cm. This port will most likely be installed in the "A" or "F" port locations of Figure 2.

The second port currently being used is a high resolution vertical beam tube. The vertical cross section of this port is shown in Figure 5 and a detailed cross section of the tube is shown in Figure 6. The vertical port has an entrance beam diameter of 2.06 cm. and a half-angle divergence of 0.071 degrees. A series of baffles are used in the tube to reduce scattered neutron and gamma contribution to the beam. Again, there are two different imaging planes available with the vertical beam port. The one most commonly used is 15.24 cm. above the exit of the tube which results in a L/D of 326. The second imaging plane is 183 cm. above the tube exit with a resulting L/D of 407. The beam diameter at the first imaging plane is 7.1 cm with a thermal flux of 2.3×10^6 neutrons/cm^2 sec., a gamma content of 2.6 R/hr and a cadmium ratio of approximately 200. This vertical port is used primarily for small objects where high resolution is needed using both film and a high resolution neutron radioscopic imaging system. The high

L/D and high cadmium ratio makes this port uniquely suitable for situations where high resolution and/or low sensitivity is needed. Using this port, neutron radioscopic images of fluid flow through 50 micron channels and pores have been obtained and liquid crystal inclusions have been imaged using high resolution lithographic film on the order of a few tenths of a micron[7].

NEUTRON RADIOSCOPIC IMAGING SYSTEMS

Three neutron radioscopic imaging systems are currently in use at PML. The first consists of an 20.3 cm. x 20.3 cm. 3M Trimax(2, 4 or 12) gadolinium oxisulfide screen mounted in a light tight box, a front surface mirror to reflect the image at right angle to the screen, a f/=0.8 lens, and an EMI magnetically focused image intensifier tube. The EMI image intensifier is then viewed by an extended red neuvicon camera and the video signal is input into a Quantex QX-9200 image processing system as shown in Figure 7. This is an IBM 9002 laboratory computer based real time image processing system. A library of several pre-programed image processing routines as well as several custom routines written by the PML staff is available for computerized enhancement and measurements. This system is used where large fields of view are needed. The Trimax screens are interchangeable depending on the requirements of the imaging session. This imaging system is quite large and bulky and is difficult to locate in the proximity of the object that is being examined.

The other two neutron radioscopy systems use a modified LIXI scope called a LIXI Neutron Imaging Detector (LIXI NID) manufactured by LIXI Inc., Downers Grove, Illinois.[8,9]. The LIXI scope was initially developed for single photon counting and was later modified to include a gamma source for NDT inspection of small objects. This device uses an input phosphor(5 cm in diameter) that is high in gadolinium to generate a light image outside the vacuum envelope of a high gain visible light micro-channel plate image intensifier tube. Currently, two different input phosphor screens are used in the LIXI NIDs. In order to avoid lateral light spread and degradation of resolution, both the input and output face plates are fiber optically coupled to the intensifier. Because the LIXI NID is completely portable and relatively small in size(51mm input diameter), it is easily placed in an area where internal dynamic motion is to be observed. The LIXI NID systems are also viewed by an extended red neuvicon camera with the video signal sent to the aforementioned Quantex image processing system. The LIXI NID systems are used on both the horizontal and vertical beams. Using the high resolution screen in the LIXI NID, oil and water flow in porous media have been imaged in pore sizes ranging from 50-200 microns with excellent results.

NEUTRON RADIOGRAPHIC DETECTORS

For film neutron radiographic imaging, several converter screens are available to convert the non-ionizing neutrons into an ionizing form of radiation. For high resolution imaging, the most commonly used screen is a 25 micron, vapor deposited gadolinium metal screen placed in intimate contact with the film such as shown in Figure 8. The gadolinium is vapor deposited on a metal backing, such as aluminum or magnesium, and covered with a 85 milli-micron coating of sapphire. This screen produces Auger electrons which are used to expose the film. When this screen is used with Kodak SR film resolutions on the order of 50 lp/mm can be obtained[10]. For radiographic applications where such high resolution is not needed other screens or films can be used. These include 1) NE426 LiF/ZnS screen(converts the neutron image into a light image), 2) 3M Trimax gadolinium oxysulfide screens(converts the neutron image into a light image) 3) indium or dysprosium transfer screens(convert the neutron image into an induced radioactivity gamma image), 4) boron nitride screens(converts the neutron image into an alpha image) and/or 4) Kodak AA, T, or M films(lower resolution, more sensitive) or track etch films.

The above light emitting screens were used in the first generation neutron radioscopy imaging systems in a manner such as that shown in Figure 9. The above described EMI system is such a system. The screens converted the neutron image into light images which were either intensified using various image intensifier designs or viewed directly with low light cameras such as the ISIT cameras. Various configurations were developed depending on the need and room available. The second generation neutron radioscopic imaging systems generally incorporated the neutron converter screen into the input photocathode of an intensifier(Precise Optics) or the camera(Old Delft). The LIXI NID systems are an example of this type of neutron radioscopic system and can be represented as shown in Figure 10. Another example of this type of detector is shown in Figure 11, where the input screen is vapor deposited gadolinium deposited directly on the input face of a micro-channel plate image intensifier. This type of detector has several inherent limitations and we are no longer investigating this type of detector at PML. These detectors show a progression from the screen being external to the electronic imagers to incorporation of the neutron converter into the electronic detector. The next generation of neutron radioscopic detectors will most likely incorporate the newly emerging and fast growing technologies of the CCD. A generic example of this type of device is depicted in Figure 12. In this example, the camera becomes the neutron converter and the limiting resolution becomes a function of the pixel size of the CCD chip. Several different designs in this vein are being explored at PML and working prototypes are expected to be ready for testing within a year.

CONCLUSIONS

This paper has presented the design and characteristics of the neutron radiographic beam ports and the neutron radioscopy imaging systems currently in use at the University of Michigan, Phoenix Memorial Laboratory. The direction of beam port improvements and potential future neutron radioscopic imaging systems have also been discussed. Additional characterization of the current and future beam ports in terms of the modulation transfer function is being pursued at PML and will be presented in a future paper.

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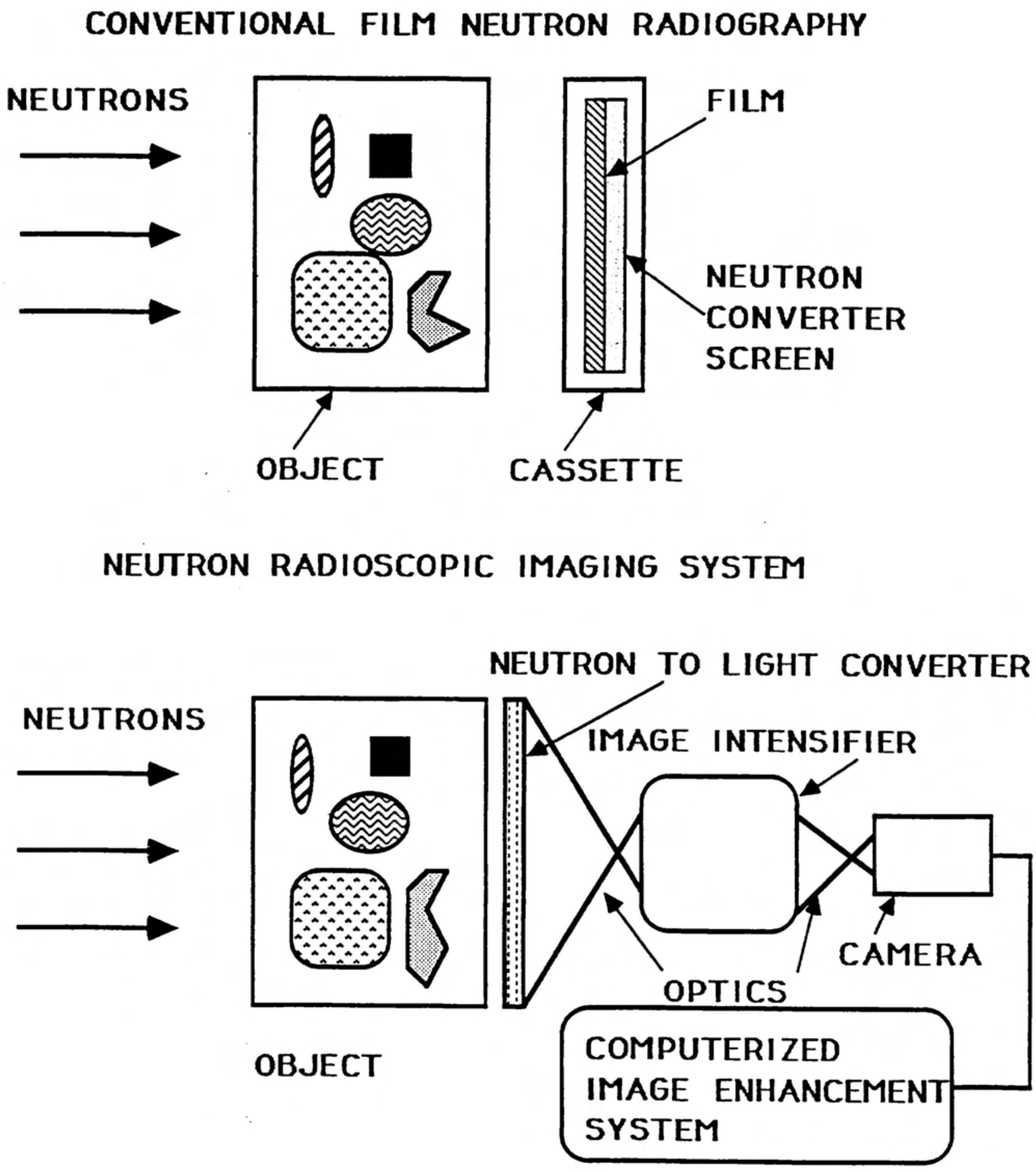

Figure 1. Comparison of film neutron radiography with neutron radioscopy.

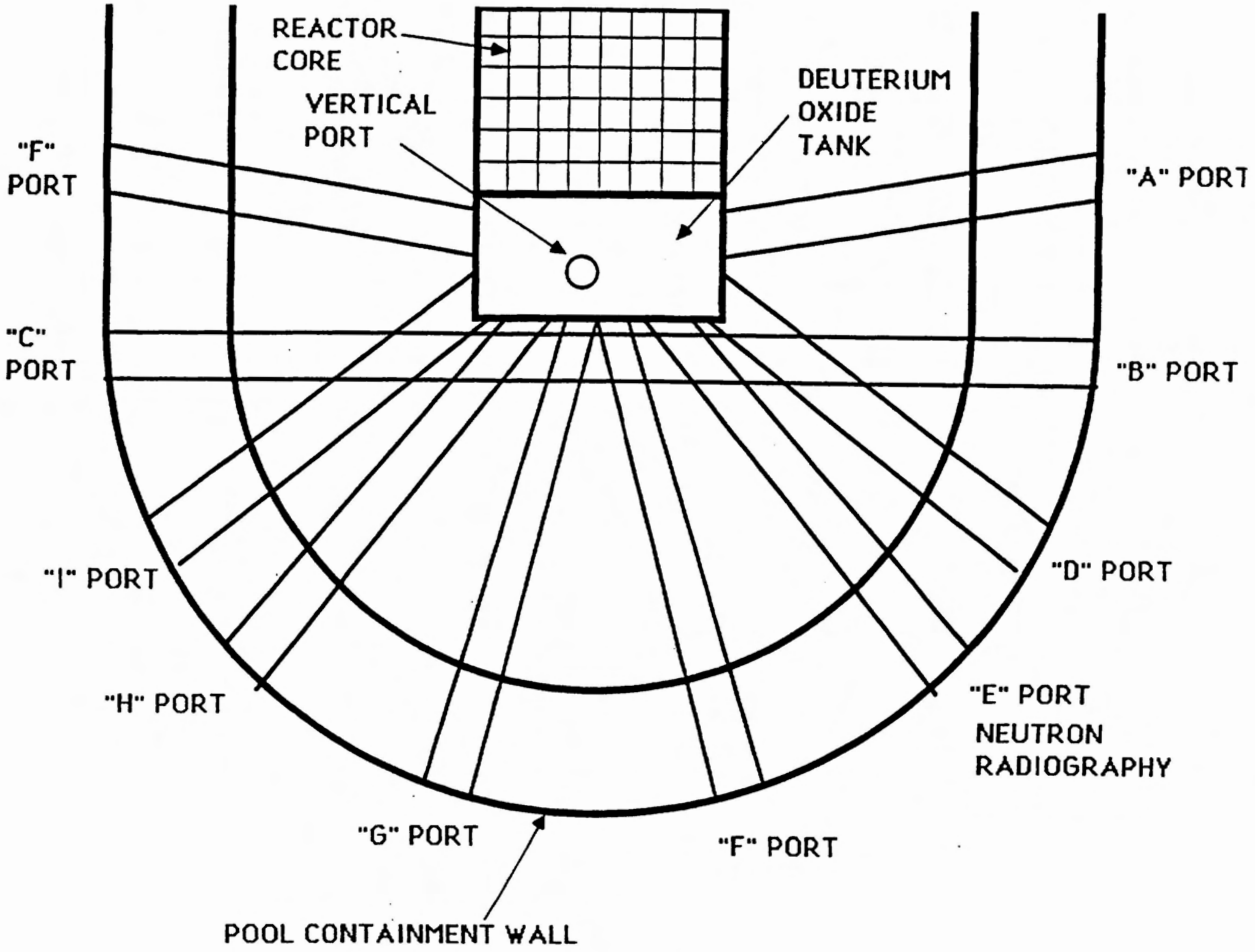

Figure 2. Cross section of FNR showing the reactor core, the deuterium oxide tank, and the beam ports.

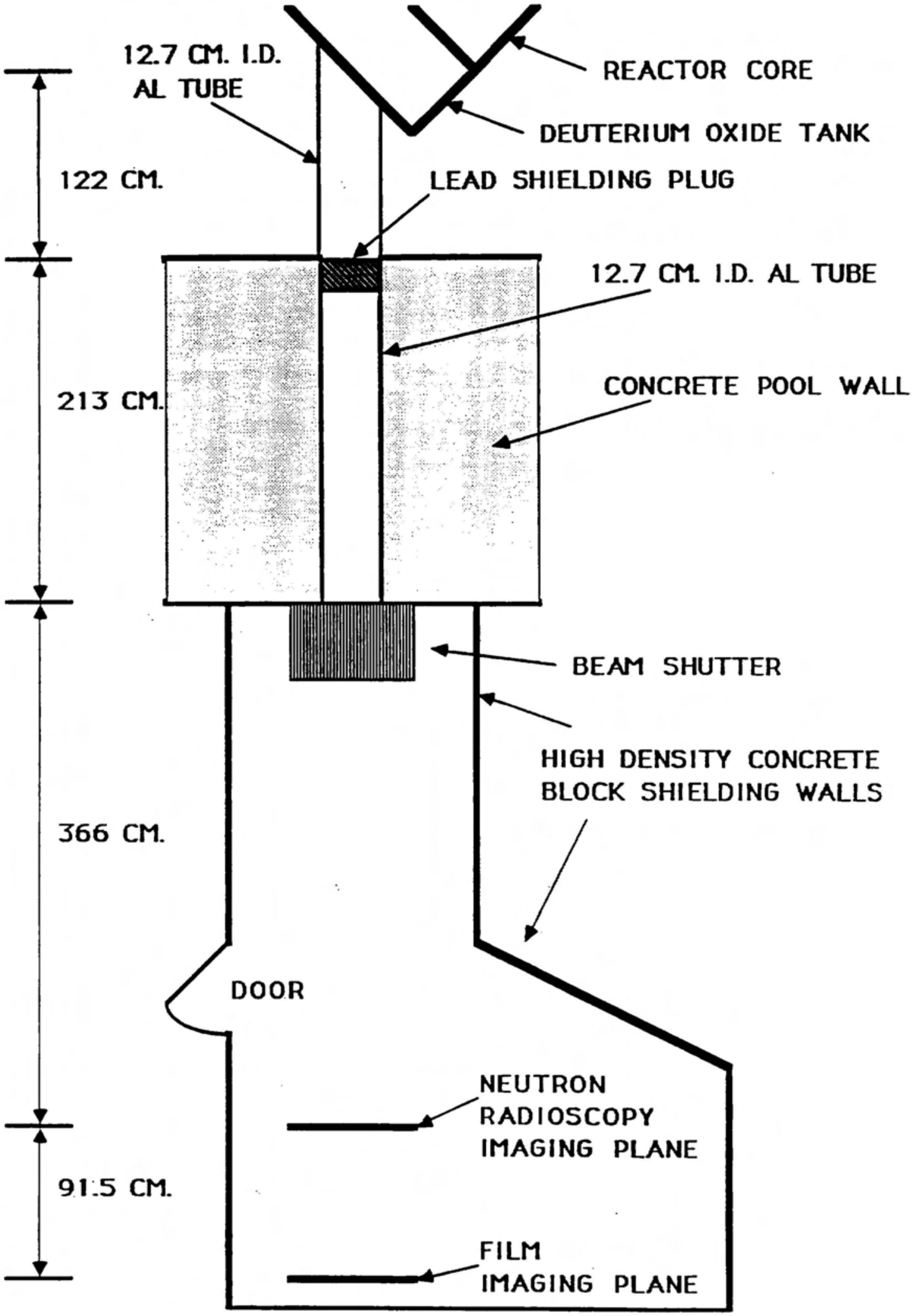

Figure 3. Spatial relationships of the horizontal neutron radiography port.

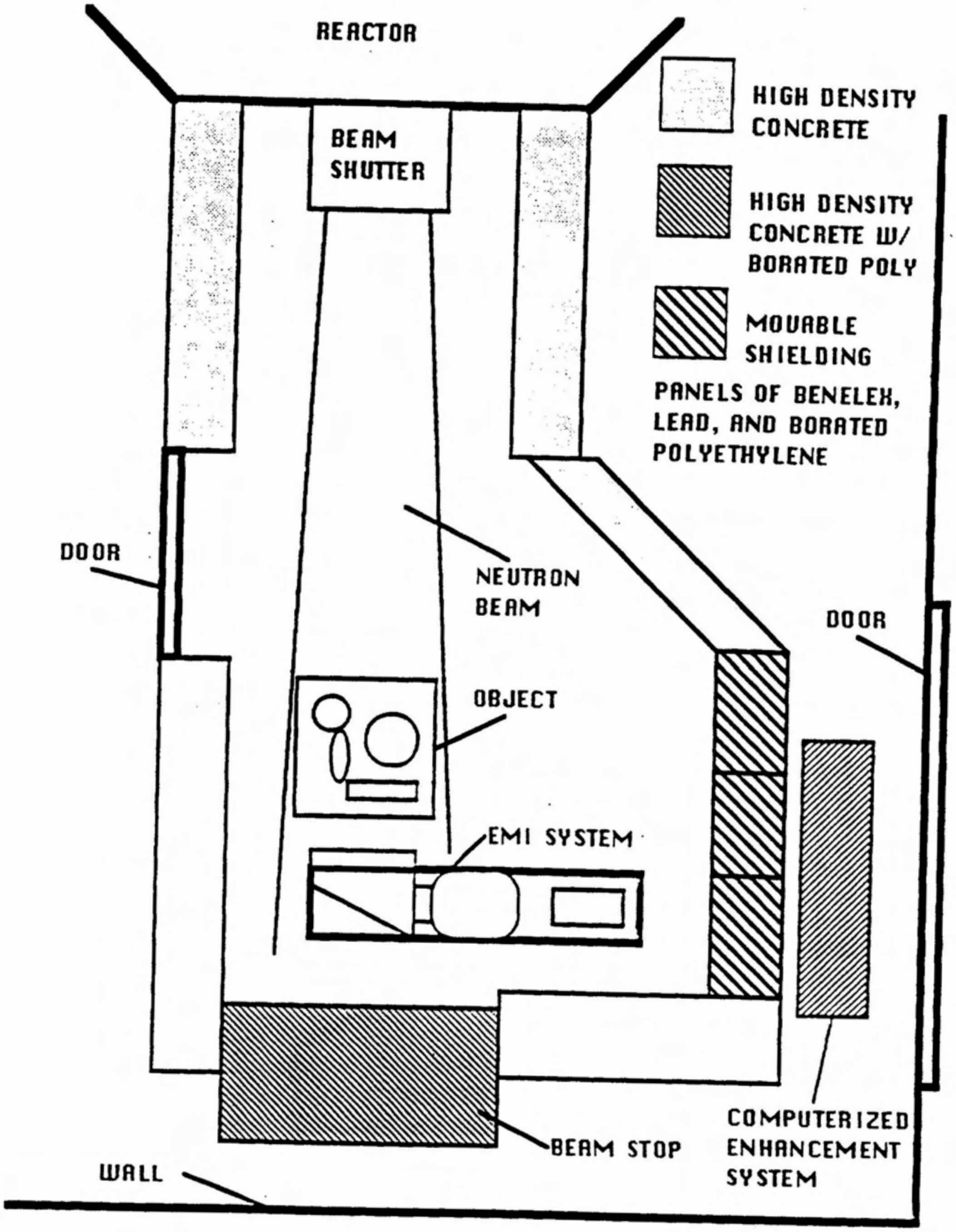

Figure 4. Construction materials used in the horizontal neutron radiography port.

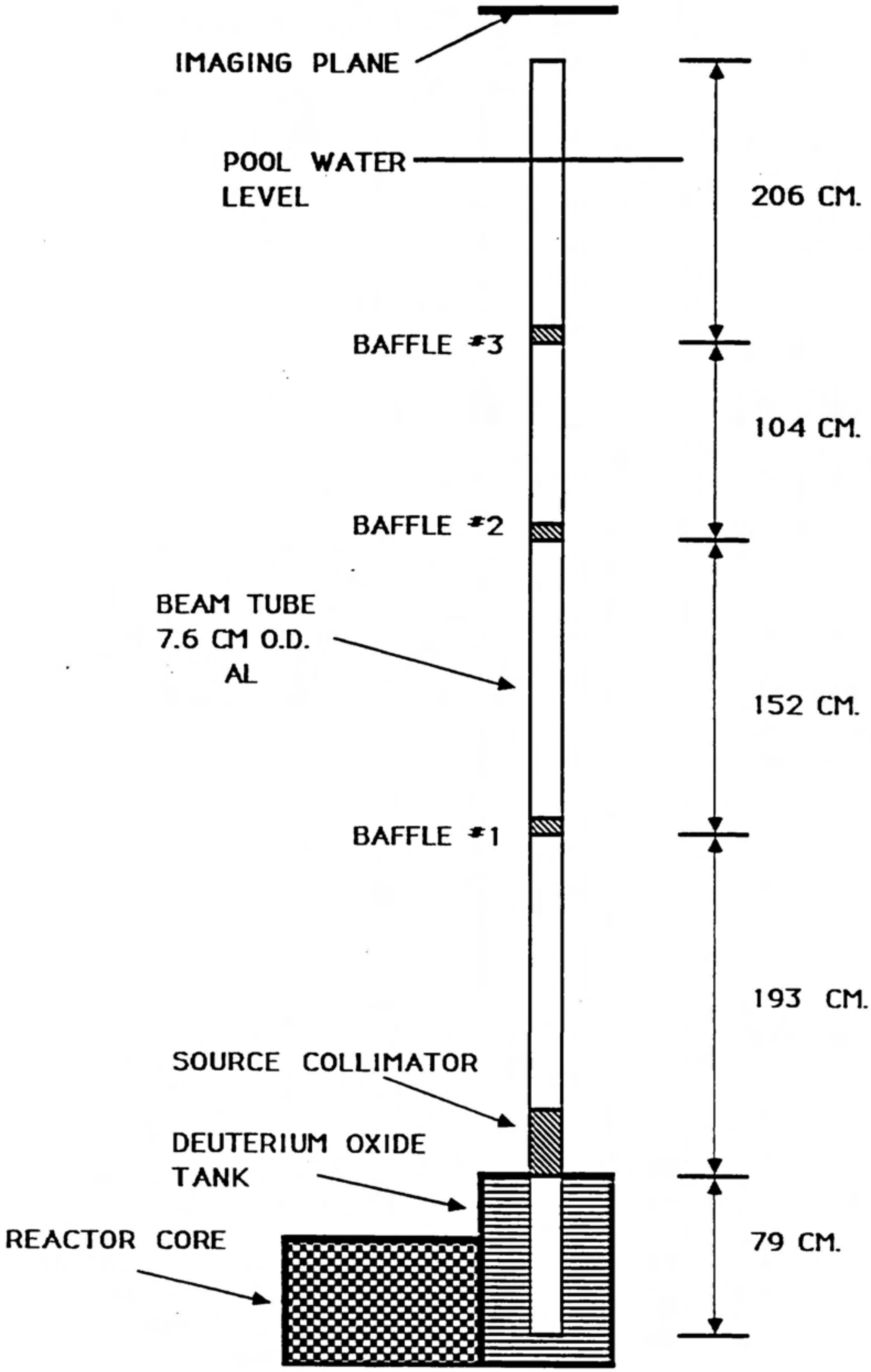

Figure 5. Cross section of the vertical neutron radiography port.

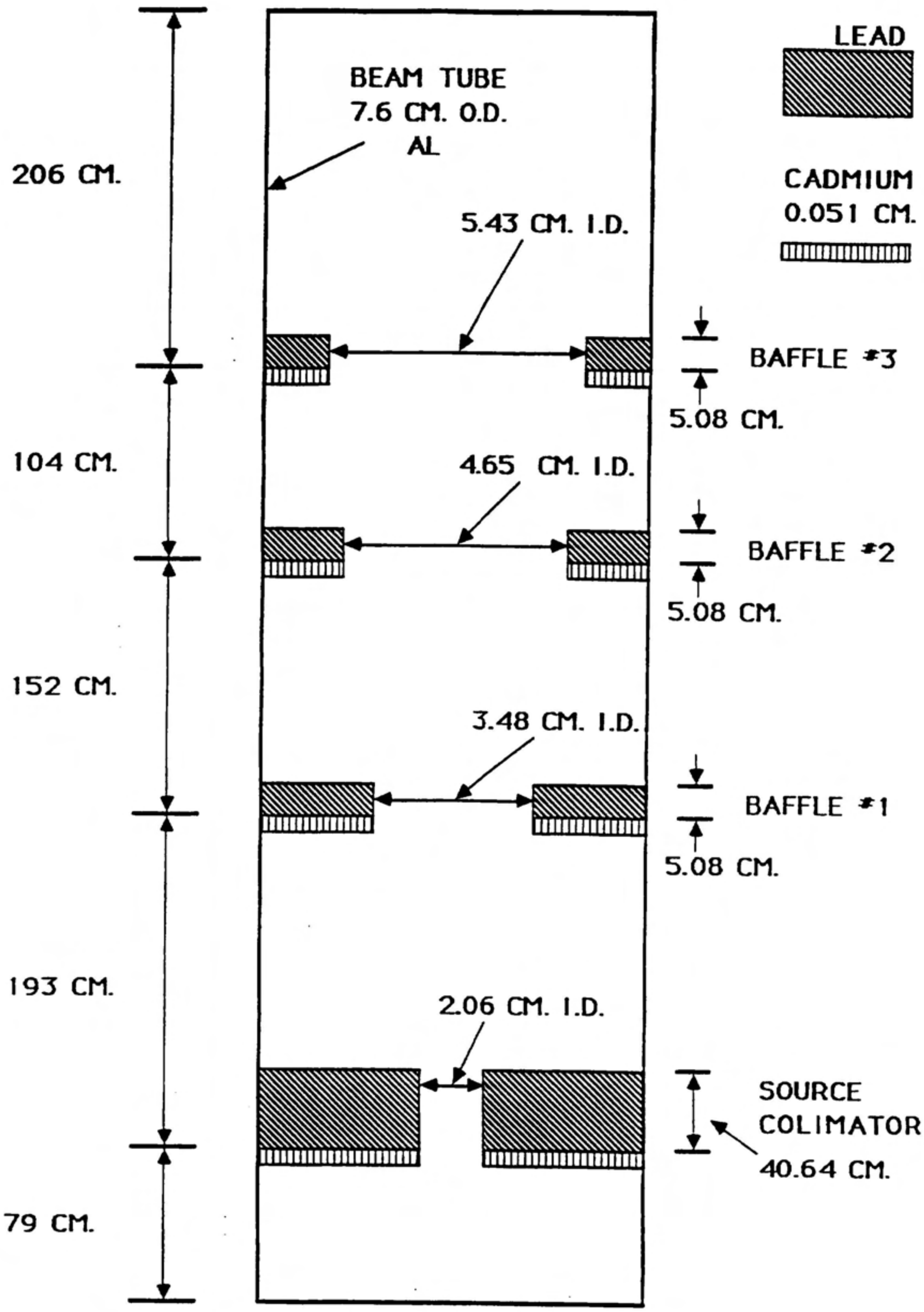

Figure 6. Details of the internal structure of the vertical beam tube.

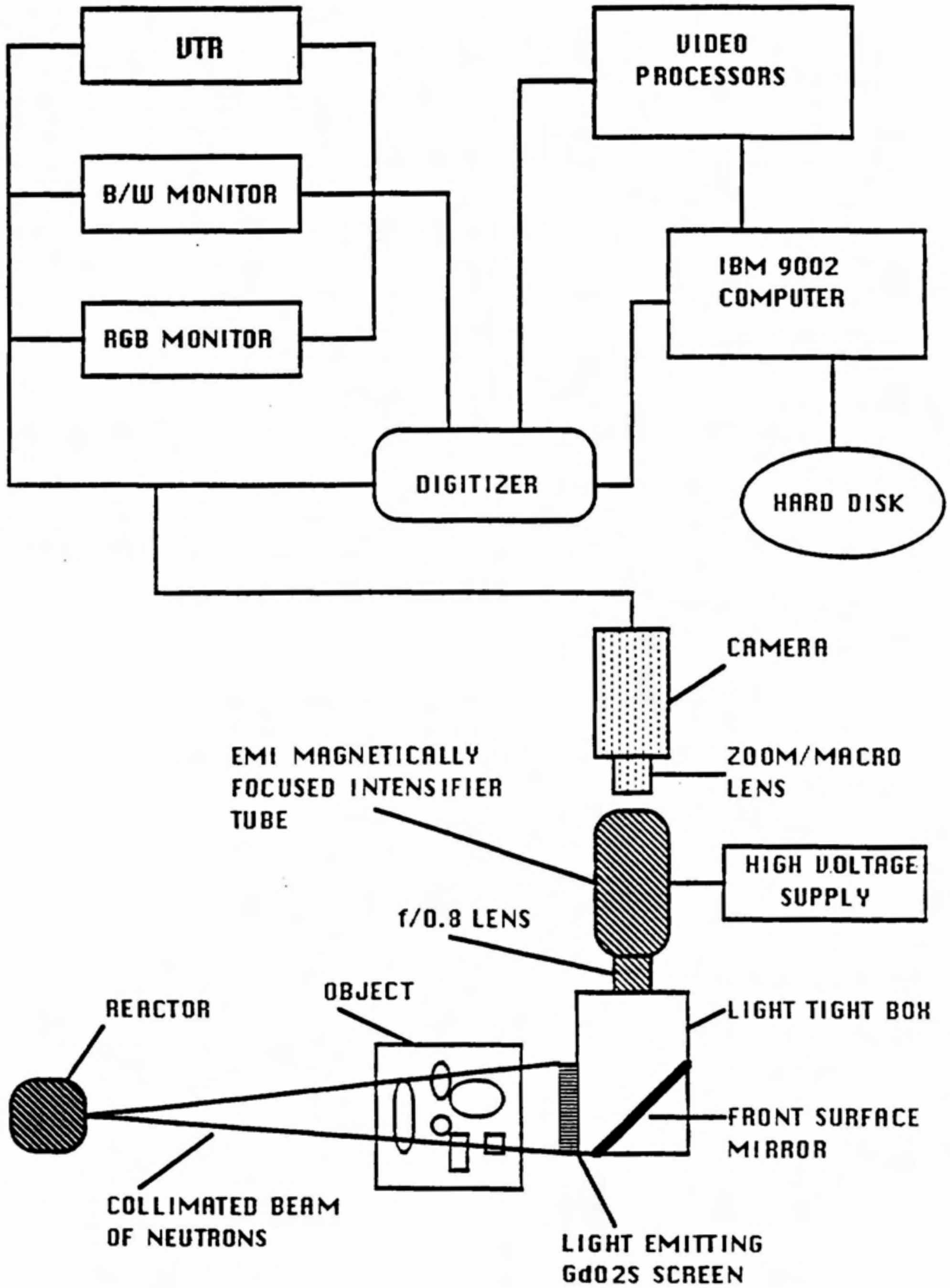

Figure 7. Schematic representation of the EMI neutron radioscopy imaging system.

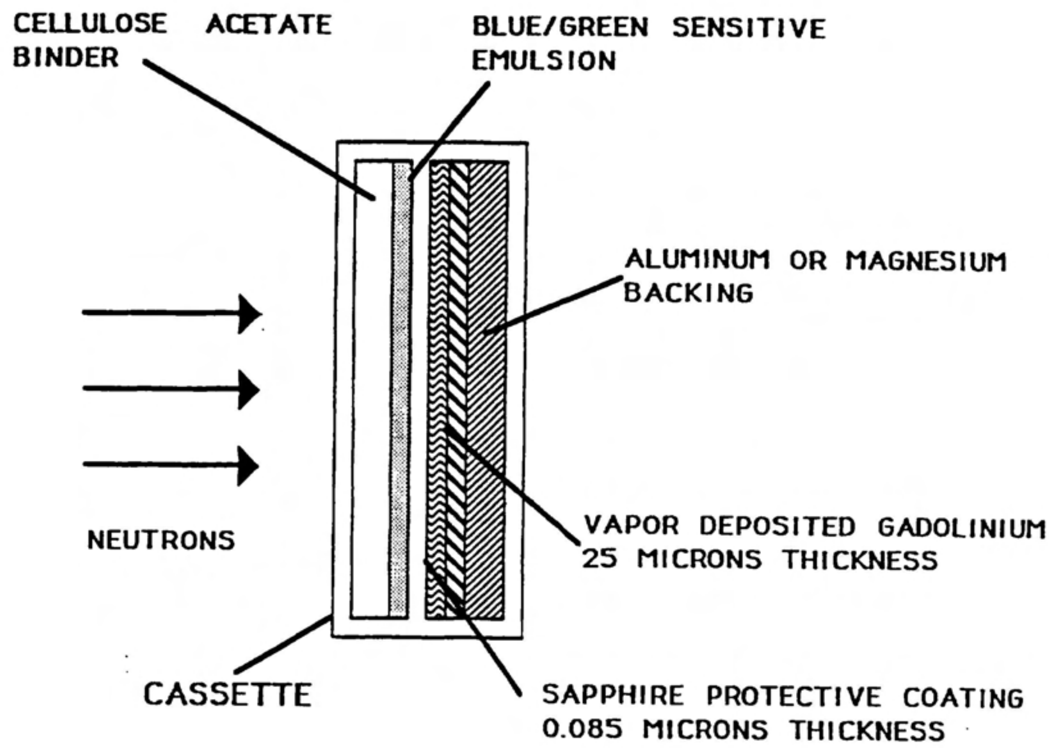

Figure 8. Example of film neutron radiography.

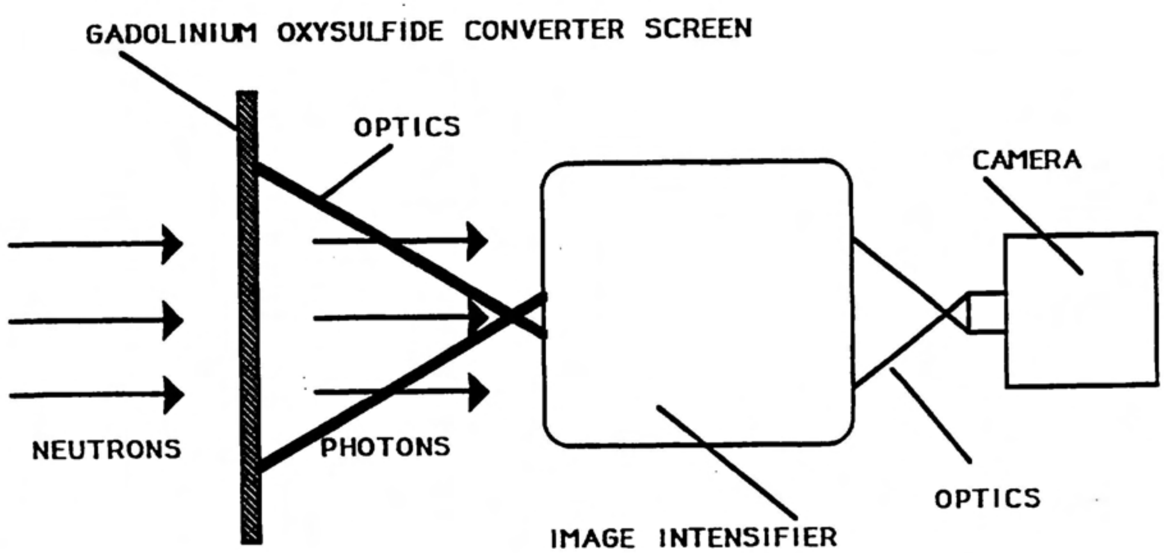

Figure 9. Example of the first generation neutron radioscopy imaging systems.

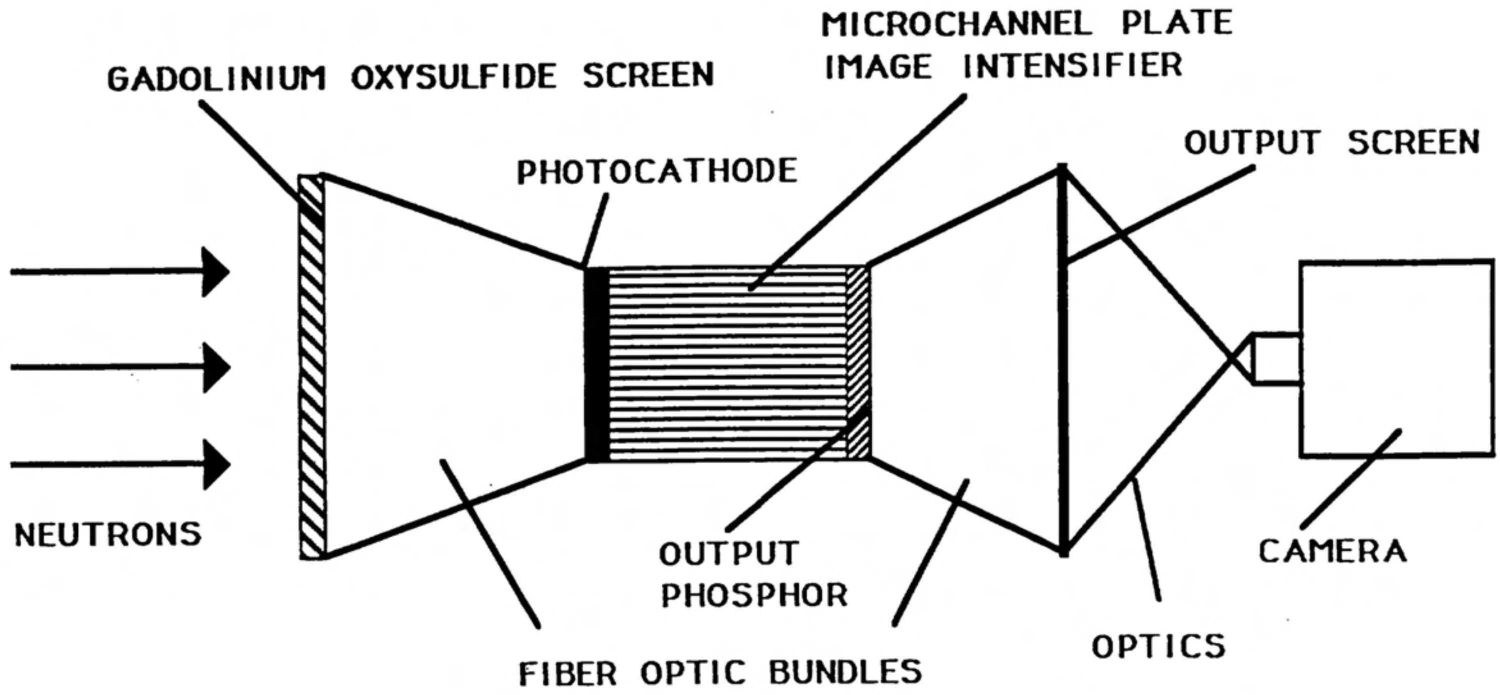

Figure 10. Representation of the LIXI NID neutron radioscopy imaging system.

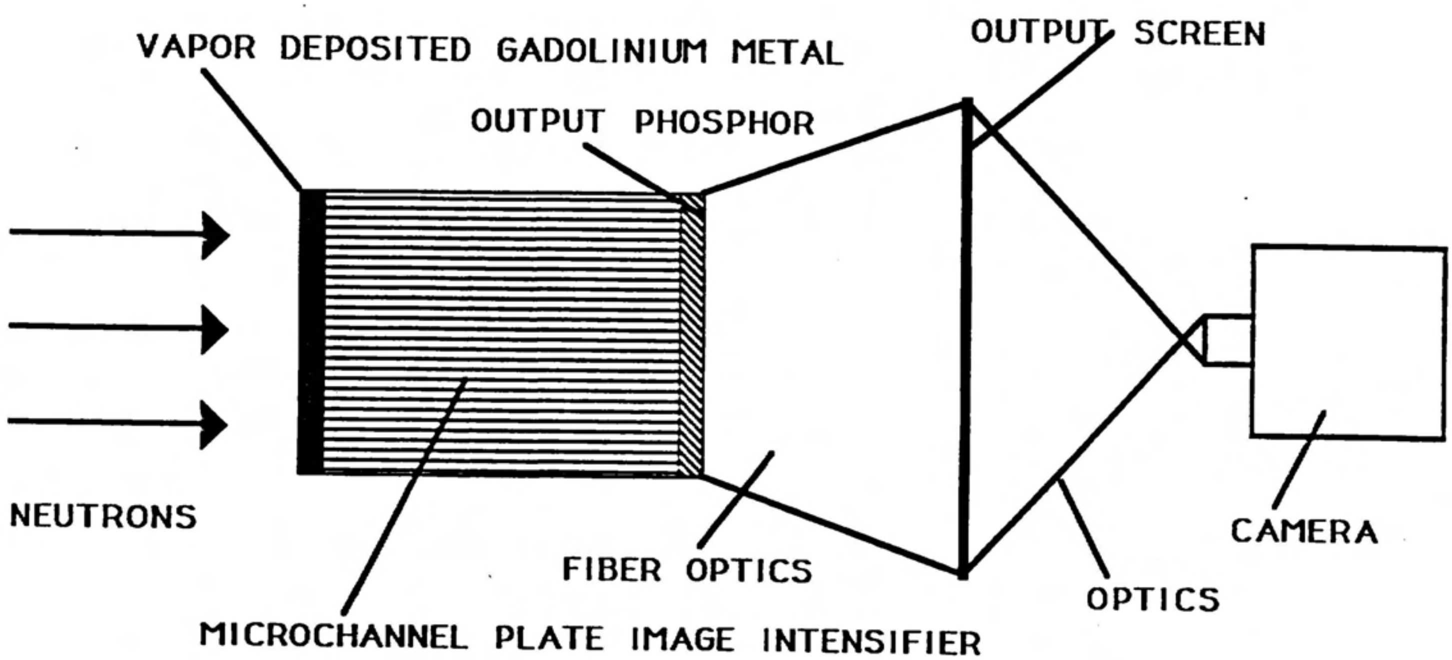

Figure 11. Modification of the LIXI NID neutron radioscopy system tested at PML.

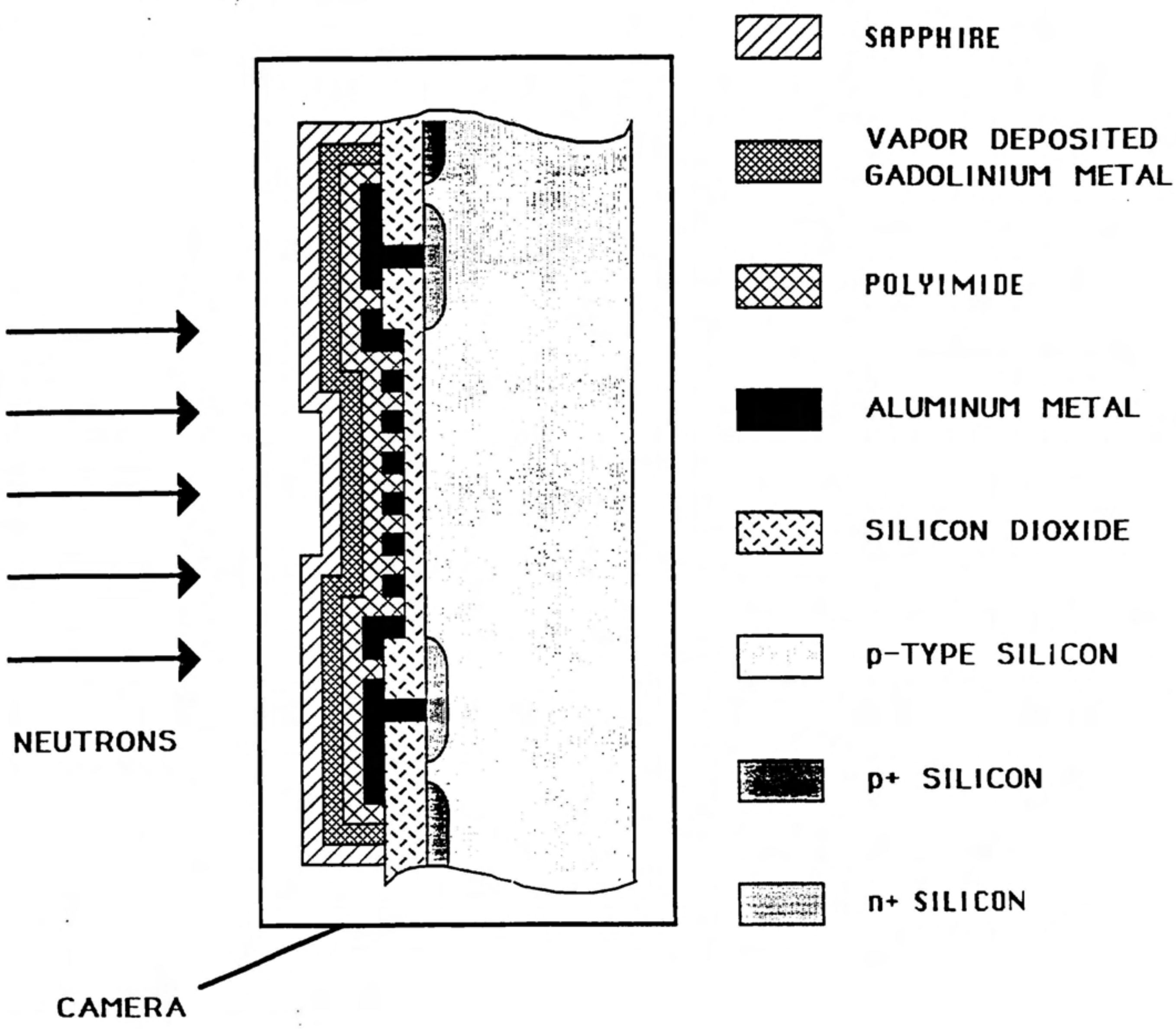

Figure 12. Generic example of a future neutron radioscopy device incorporating CCD technology.