# THE STATIONARY NEUTRON RADIOGRAPHY SYSTEM: A TRIGA-BASED PRODUCTION NEUTRON RADIOGRAPHY FACILITY

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ABSTRACT

General Atomics (GA) is under contract to construct a Stationary Neutron Radiography System (SNRS) - on a turnkey basis - at McClellan Air Force Base in Sacramento, California. The SNRS is a custom designed neutron radiography system which will utilize a 1000 KW TRIGA reactor as the neutron source. The partially below-ground reactor will be equipped with four inclined beam tubes originating near the top of the reactor graphite reflector and installed tangential to the reactor core to provide a strong current of thermal neutrons with minimum gamma ray contamination. The inclined beam tubes will terminate in four large bays and will interface with rugged component positioning systems designed to handle intact aircraft wings, other honeycomb aircraft structures, and pyrotechnics. The SNRS will be equipped with real-time, near real-time, and film radiographic imaging systems to provide a broad spectrum of capability for detection of entrained moisture or corrosion in large aircraft panels.

GA is prime contractor to the Air Force for the SNRS and is specifically responsible for the TRIGA reactor system and a portion of the neutron beam system design. Science Applications International Corporation and the Lionakis-Beaumont Design Group are principal subcontractors to GA on the project.

## INTRODUCTION

Neutron radiography is a mature non-destructive inspection technique and has been used successfully for many years to detect the presence of hydrogen-containing materials inside of, or behind metal structures. Accordingly, the use of neutron radiography to inspect aircraft wings and control surfaces for the presence of moisture or corrosion in aluminum honeycomb assemblies is straightforward and has been demonstrated on a piece-parts, low throughput basis. The use of real-time imaging with x-radiography and neutron radiography does not have as long a history of demonstrated performance, but has emerged within the past several years as an alternative to film imaging where high throughput of objects to be radiographed is desired, and this type of imaging permits rapid scanning of objects and concentration on specific areas of interest. The real-time scanning of objects through a fixed neutron beam requires a programmable and precisely reproducible component positioning system. With the current state-of-the-art of robotic systems, this capability is currently available with modest development.

The combination of a high intensity TRIGA reactor neutron source, real-time imaging and data storage and retrieval, and a ruggedized and reliable programmable component positioning system form a solid technical basis for establishing the Stationary Neutron Radiography System (SNRS). The primary mission of the SNRS is to non-destructively inspect F-111 aircraft wings to detect moisture or corrosion on a relatively high throughput production basis.

The SNRS (figure 1) consists of a shielding and containment system, TRIGA Reactor System, Neutron Beam System, Component Positioning System, Neutron Imaging System and Image Interpretation System. Each of these systems will be briefly described in the sections which follow.

## SHIELDING AND CONTAINMENT SYSTEM

The SCS is a rectangular enclosure (1370 $M^2$) incorporating the TRIGA reactor neutron source, four neutron radiography bays, staging areas, equipment areas, offices and control rooms (figure 2). Although the SCS is designed to ultimately accept and interrogate space shuttle solid rocket boosters, intact F-111 aircraft wings will be the largest items to be inspected initially within the facility.

The SCS is designed with shielding and shutters to permit manned access to a radiography bay while the reactor is at full power and the other bays are in use. The staging area shielding walls are designed such that the increase in dose ratio due to the operation of the facility does not exceed 0.2 mR/hr, and radiation monitors are provided to measure the radiation level in the gaseous effluents from the facility (figure 3). A drain line and sump are provided to monitor the amount and activity of any water collecting as a result of reactor tank leakage (figure 4). A hatch is provided in the ceiling of the reactor room to allow long items to be inserted or removed from the reactor.

## TRIGA REACTOR SYSTEM

The reactor system is a standard design 1000 kW, natural convection-cooled TRIGA reactor with the graphite reflector modified to accept the source ends of the four neutron radiography beam tubes which terminate in four separate neutron radiography bays. The reactor is located near the bottom of a water-filled aluminum tank 7 ft in diameter and about 26 ft deep. The tank is surrounded by concrete shielding on the sides and bottom. Access to the core is through the water from the open top of the tank (figure 5). The water provides adequate shielding at the top of the tank. The control rod drives are mounted at the top of the tank on a bridge structure spanning the diameter of the tank. The reactor is monitored and controlled by a state-of-the-art computer-based instrumentation and control system featuring color graphics display, self-calibration, and automatic logging of vital information (figure 6). Both manual and automatic control options are available to the operator.

TRIGA fuel is characterized by inherent safety, high fission product retention, and the demonstrated ability to withstand water quenching with no adverse reaction from temperatures to 2012° F. The inherent safety of this TRIGA reactor has been demonstrated by the extensive experience acquired from similar TRIGA systems throughout the world. This safety arises from the large prompt negative temperature coefficient that is characteristic of uranium-zirconium hydride fuel-moderator elements used in TRIGA systems. As the fuel temperature increases, this results in a mechanism whereby reactor power excursions are terminated quickly and safely. A plan view of the reactor is shown in figure 7.

## NEUTRON BEAM SYSTEM

The NBS consists of a beam tube, aperture, shutter and beam stop for each of the four radiography bays. The NBS features an optimized "source end" design of the graphite reflector and beam-extraction "hole" to ensure maximum thermal flux, minimum gamma contamination, and minimum non-uniformity at the image plane. Beams with an L/D = 100:1 will provide thermal neutron flux of approximately $6.4 \times 10^6$ $n/cm^2.s$ at an operating power of 250 kW.

All four beams are capable of simultaneous operation. The apertures, located at the edge of the reactor graphite reflector are replaceable in all beam tubes. Aperture change-out is accomplished by remotely removing a section of the reactor reflector and replacing the in-tank tube section with one with the desired aperture. The reflector section is then replaced. The in-tank beam tube section also provides a means of effecting future beam upgrades (e.g., liquid-cooled filters) by providing space along the beam tube for such upgrades.

Two shutters are installed at the output end of each beam tube. A massive "biological" shutter has an "open" position and a "closed" position to allow safe personnel access to the exposure bay. A fast-operating, lightweight shutter, attached to the biological shutter, allows the thermal neutron beam to be attenuated for accurately controlling film exposures.
Beam stops built into the walls are provided in each bay to minimize the thermal neutron albedo. An elevation view showing the above-identified

design features of a typical NBS for the SNRS is shown in fig. 8. Illustrated is the neutron radiography (NR) port and its biological shield, the massive personnel beam shutter, and the TRIGA reactor.

COMPONENT POSITIONING SYSTEM

The CPS is designed to position airplane components in each of the four inspection bays. The CPS in bays 1, 2, and 3 will be totally automated and will provide five independent axes of motion.

Each of these bays is optimized to provide positioning of components by size. Bay 1 is designed to handle the largest components; the FB-111 wing being the largest (figure 9). The bay 1 CPS will accommodate all of the smaller components with proper fixturing.

Bay 2 is optimized to handle other large components. The F-111 horizontal stabilizer is the largest. This bay can also accommodate all of the smaller components with proper fixturing.

Bay 3 is optimized to handle small components up to 5 ft by 5 ft.

Bay 4 is sized to accommodate NASA's solid rocket booster (SRB) components. The bay is equipped with fixturing to hold pyrotechnics and film cassettes that are moved in and out of the inspection area manually.

NEUTRON IMAGING SYSTEM

The NIS consists of components which transform the neutron distribution into a video image. It also contains the sensors to measure the incoming neutron flux and a system to mark defects observed by the operator. These items are included in a single subsystem since they are physically combined in the NIS module that extends from a telescoping arm (figure 10).
The heart of the NIS is a 9-in.-diameter neutron-sensitive image amplifier. This device used an internal $Gd_2O_2S$ converter screen and deposited photocathodes to image and brighten the original neutron distribution to

form an image on an output phosphor. This amplified image is coupled to a high-performance Plumbicon camera through a pair of ultra-fast collimator lenses. This arrangement provides a very sensitive and wide dynamic range analog imaging system capable of producing excellent real-time radiography over two orders of magnitude of flux from $10^5$ n/cm$^2$-s to greater than 107 n/cm$^2$-s.

Built into the neutron imager are two subsystems that make its use more quantitative. These are the neutron current gauge and a defect marking system.

The neutron flux gauge consits of two small U-235 fission chambers, one located at the beam exit port and the other located beside the image amplifier. This pair of counters are read out in the counter mode by a dual scaler-timer so that their rate can be directly interpreted in current units. The two flux measurements can be used to monitor correct system operation, determine average neutron attenuation through a part, and provide a means of calibrating the neutron absorption measured by the imager. Using a remote display system, the counter outputs will be displayed on the operator console where they are easily accessible to the operator.

The defect marker system is a spray-jet ink marker. When a defect location is to be marked, the operator sprays a spot. He then moves the part to additional locations for marking. This can be done in real time while viewing the monitor, since the ink is quite visible in the neutron image. A single spot can be marked, or a series of spots to form a line around the damaged area. Neutron opaque marks along the movable arm assist the operator in describing the location of the flaw relative to the encodercoordinates of the image center. These marks can be used in the audio record as well as being entered onto the image if needed.

The entire NIS package provides a complete set of input data to the image interpretation system which then aids the operator in interpretating the image appearing on the monitor.

## IMAGE INTERPRETATION SYSTEM

The purpose of the IIS is to collect, process, and display data from the NIS in a manner which best aids the operator to interpret realtime images for detecting the presence of corrosion or other flaws. Each system operation has been optimized with this goal in mind. The choice of hardware has been, in particular, specifically selected to provide the unique characteristics required for effective real-time detection and interpretation of corrosion products on aircraft components. In addition, the IIS is capable of storing image sequences during the inspection and retrieving them later for comparison or review.

The IIS functions by digitally storing and processing images to improve their contrast and effective resolution. The IIS performs all of the standard image processing functions of noise reduction, contrast stretch, and edge enhancement through its flexible pipeline processor and multiple frame buffers. In addition, the proposed IIS uses a unique field-flattening procedure to permit the sensing of very faint quantities of corrosion in real-time images. This is accomplished by special organization of the components. This organization permits the simultaneous correction for the imager response and neutron distribution to the image, as well as image integration and processing. This is a critical feature because the indications of corrosion within the image are often smaller than the instrumental effects of the system. The system is further enhanced by an interactive contrast stretch and pseudo-color display which permit the windowing of typical neutron images into color groups that represent particular areas of the part. On a typical image, the aluminum skins and honeycomb may appear blue, the corrosion pink and the sealant nearly white. This fine separation of image contrast in a smooth and controllable way not only eases the operator's task of interpretation but further provides a quantitative means of determining the level of the corrosion problem.

Data is stored on a 1/2-in. industrial VHS video recorder. Additional capabilities are provided for storage onto a 1-gigabyte optical disk as a system upgrade. Hard-copy video images are also available within seconds to provide a convenient means of referencing images for rework orders. Video cursors, as well as keyboard alphanumeric titles, can be overlayed on the image to augment the audio commentary on the video tape record.

The images from the system are displayed on three monitors on the operator console (figure 11). The video processor can display two different images simultaneously. The third monitor is used to retrieve stored analog images from video tape to be compared with the processed data. A video switcher permits the switching of live and processed images between the monitors. All components and software used in the IIS are modular and can easily be expanded and upgraded as needed. In particular, the IIS is very well suited for advanced frequency domain processing and automated pattern recognition tasks. The proposed IIS represents the most advanced image processing equipment commercially available and will provide a long service life of high-performance operation in the SNRS project.

## SUMMARY

GA is prime contractor for the Stationary Neutron Radiography System, which will be used to inspect aircraft wings and control surfaces for moisture or corrosion on a high throughput production basis. Construction at the McClellan Air Force Base site began in September 1987, and will be completed in late 1988. Figures 12 and 13 show progress at the site. It is expected that the TRIGA neutron source will start up in the first quarter of 1989, and the facility will be turned over to the Air Force by the end of 1989.

GENERAL ATOMICS

# STATIONARY NEUTRON RADIOGRAPHY SYSTEM



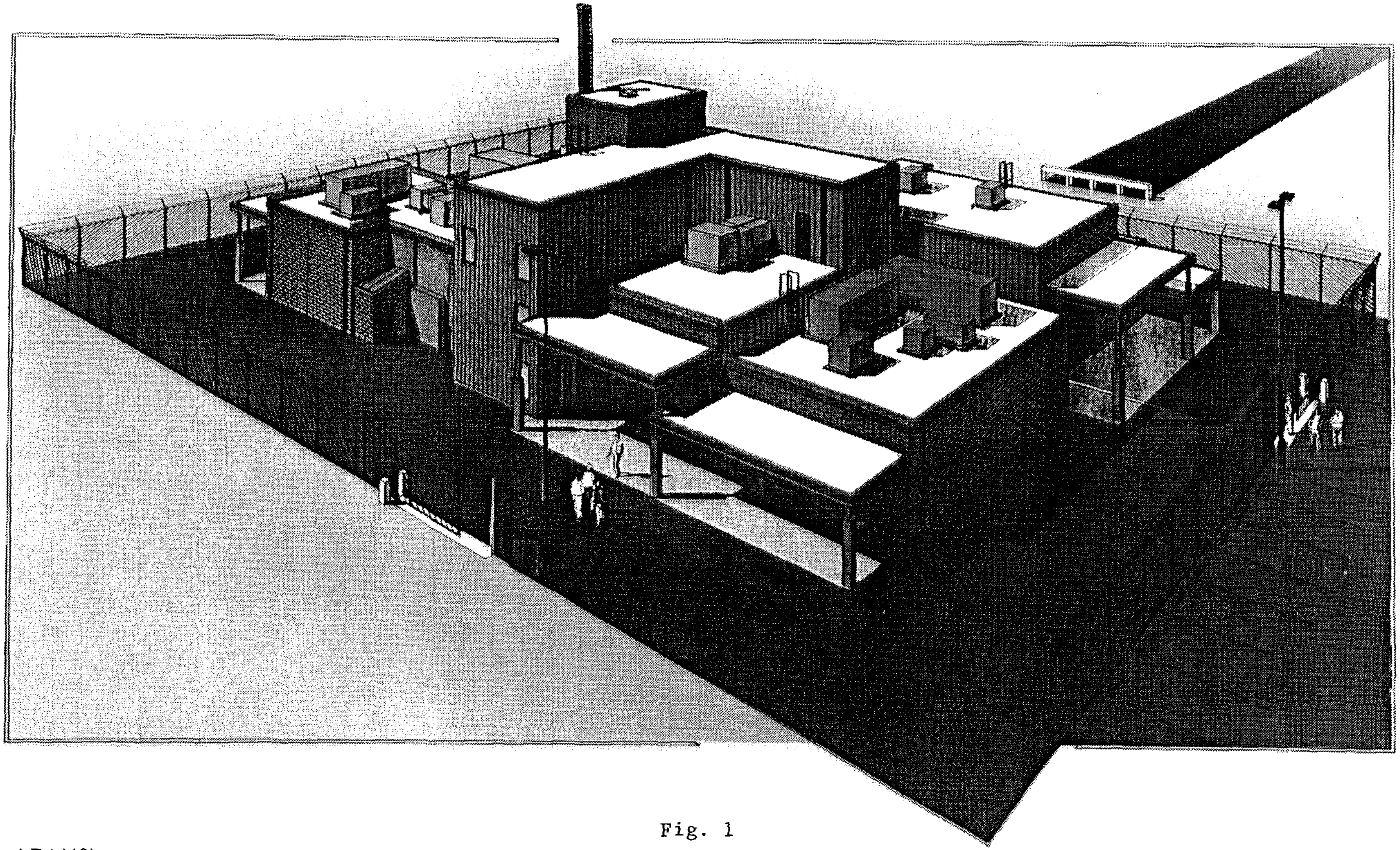

Fig. 1

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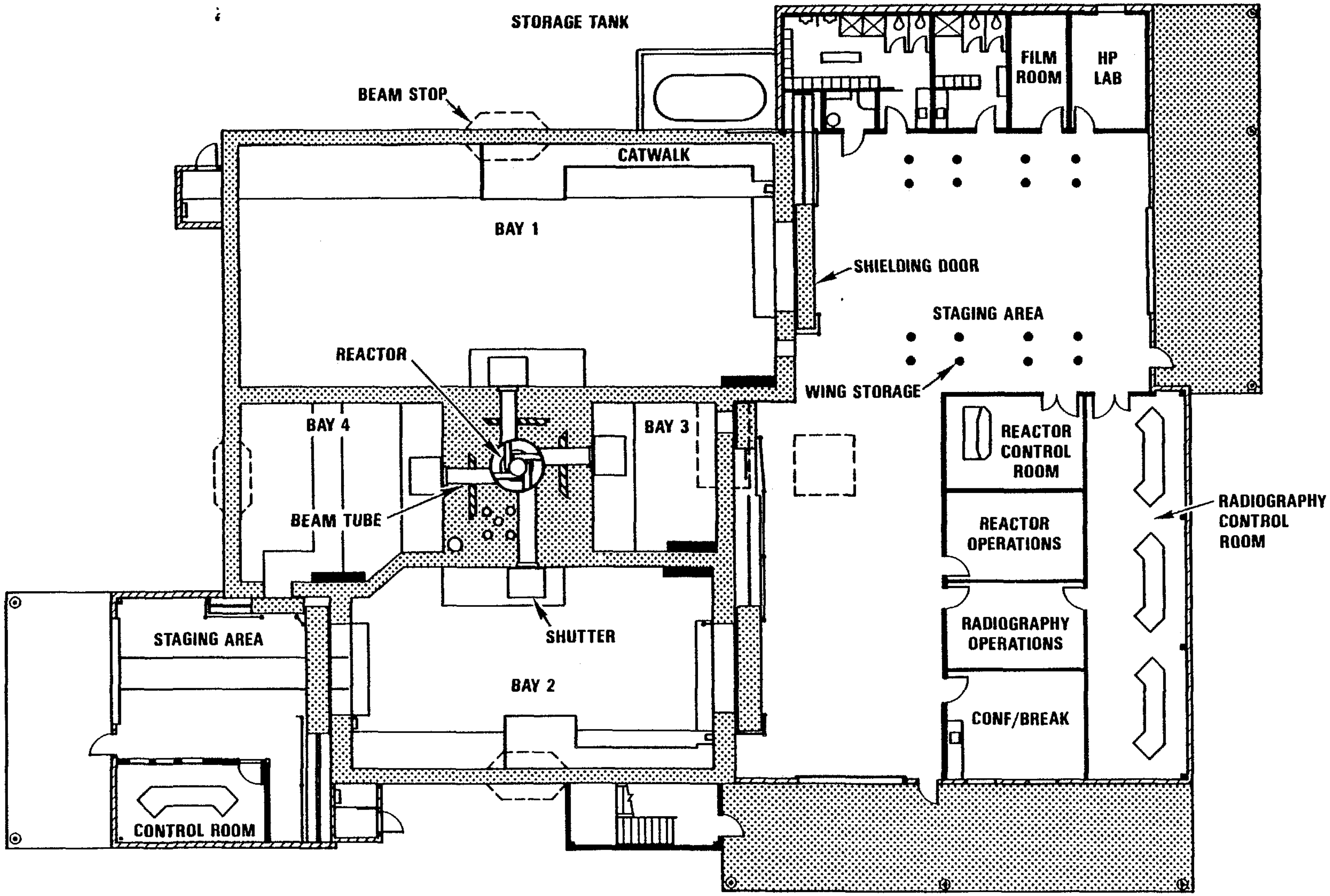
GENERAL ATOMICS

# STATIONARY NEUTRON RADIOGRAPHY SYSTEM ENCLOSURE



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12-2-87

Fig. 2

# SNRS SECOND FLOOR PLAN VIEW



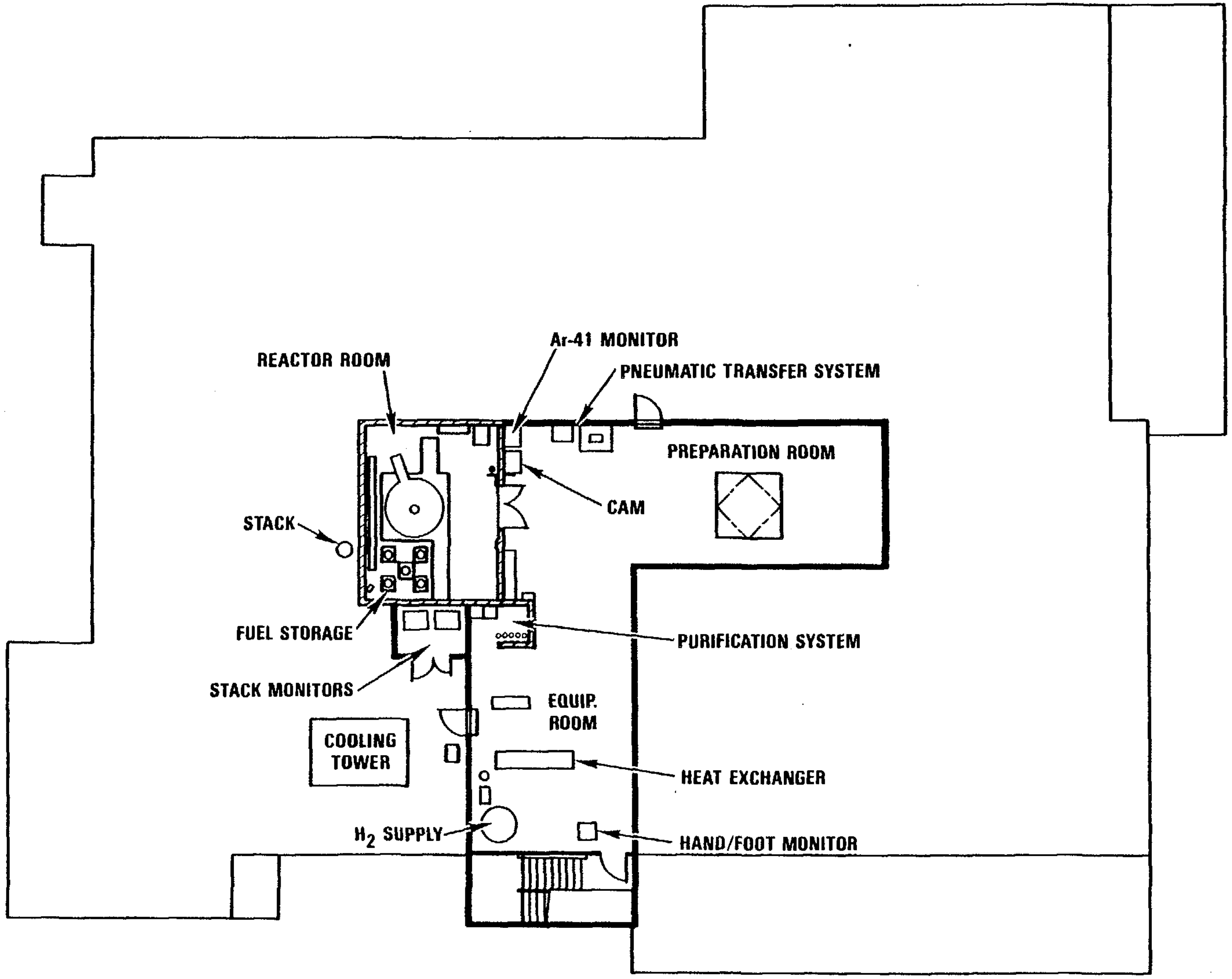


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Fig. 3

# SNRS ELEVATION SECTION B-B



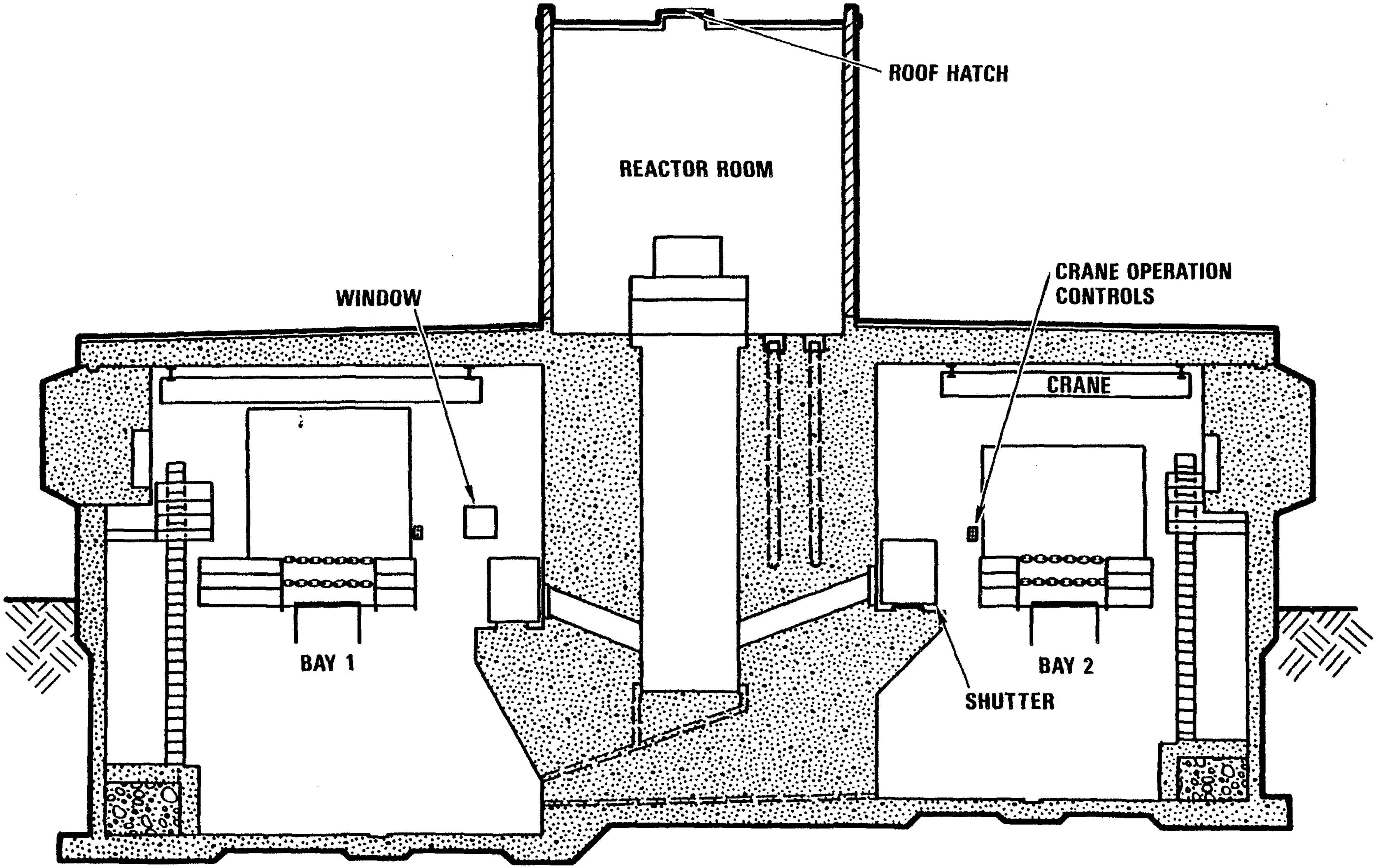


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Fig. 4

# VIEW FROM TOP OF REACTOR TANK



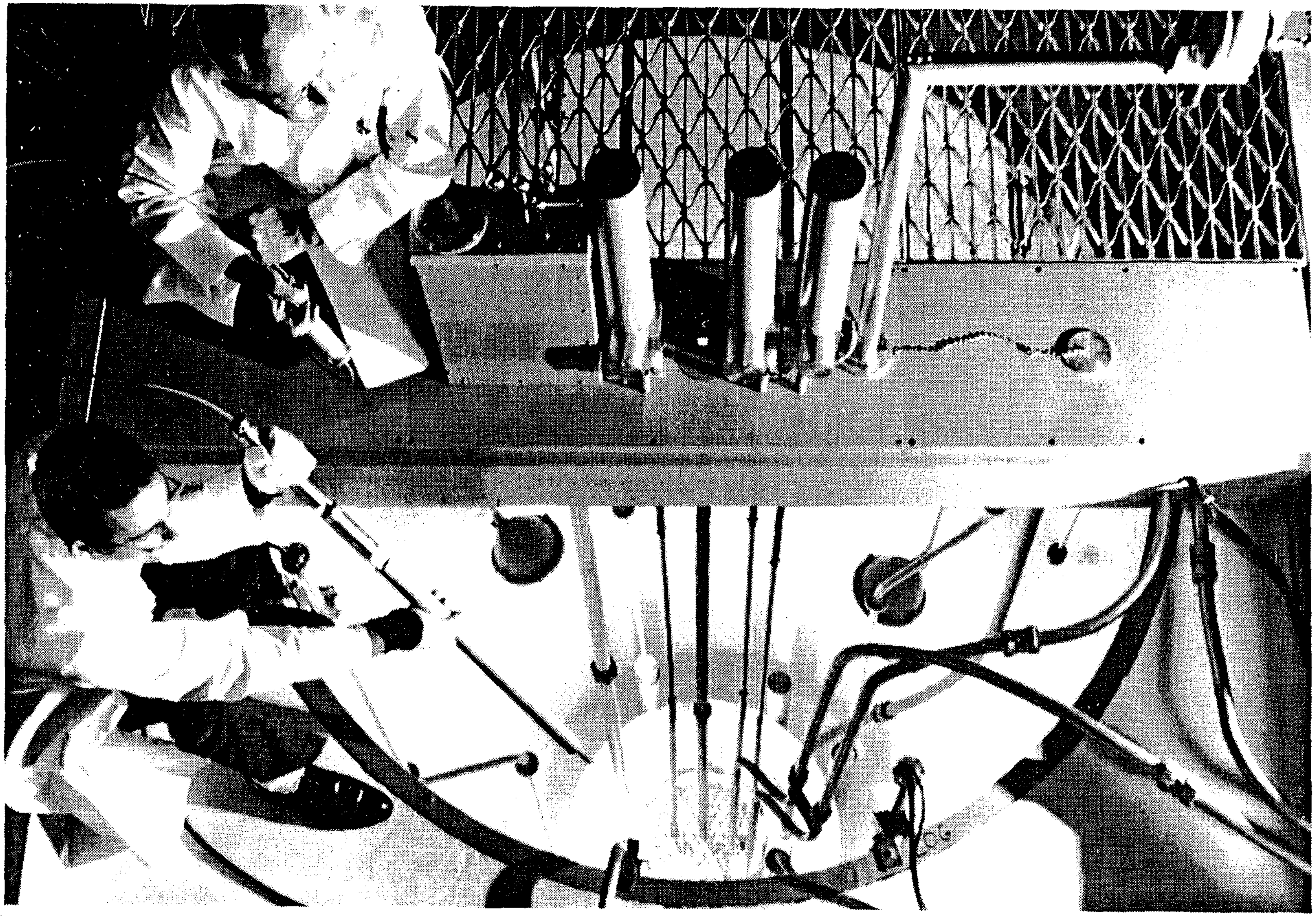

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Fig. 5

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# REACTOR CONTROL CONSOLE



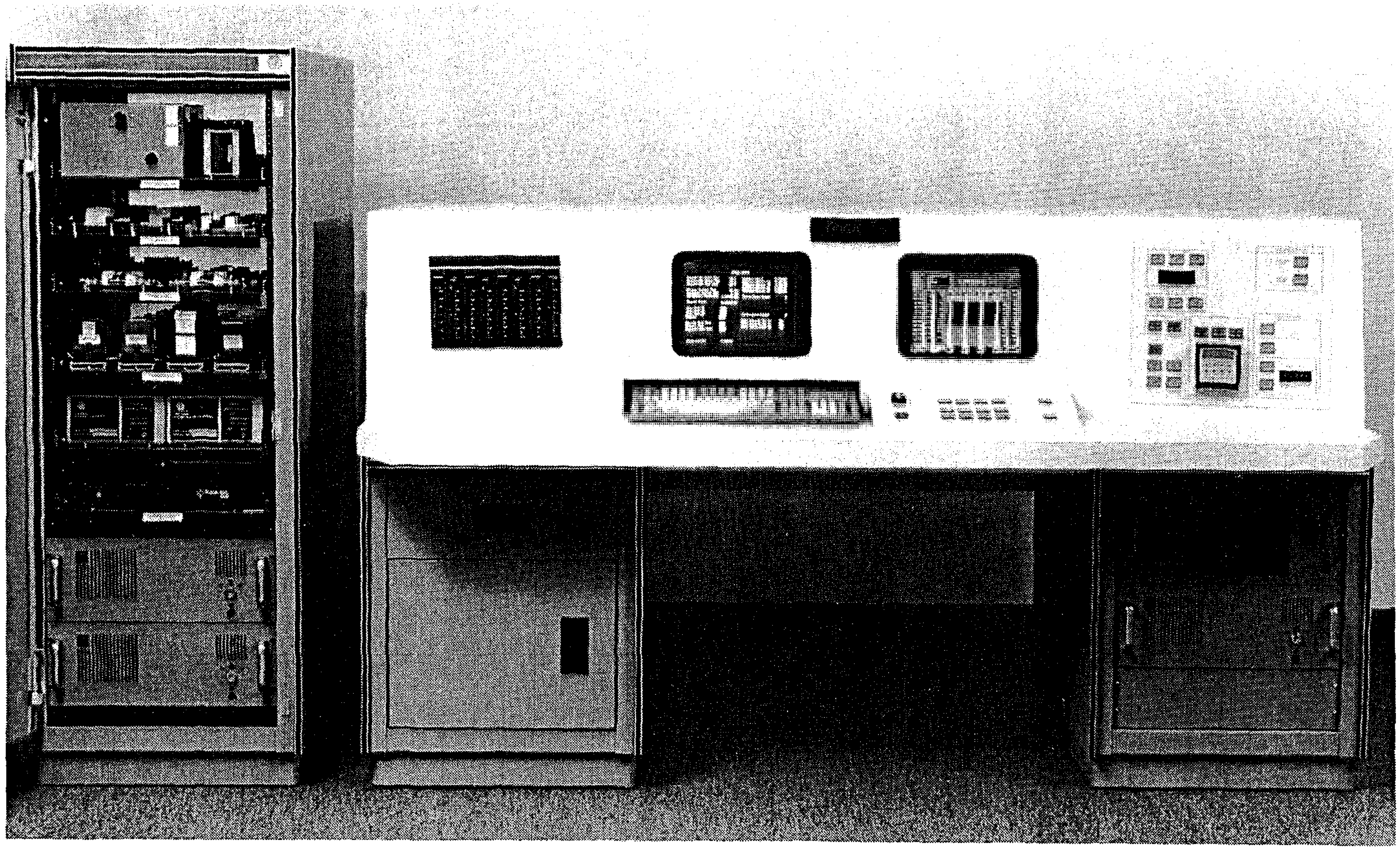

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Fig. 6

# PLAN VIEW SNRS TRIGA REACTOR

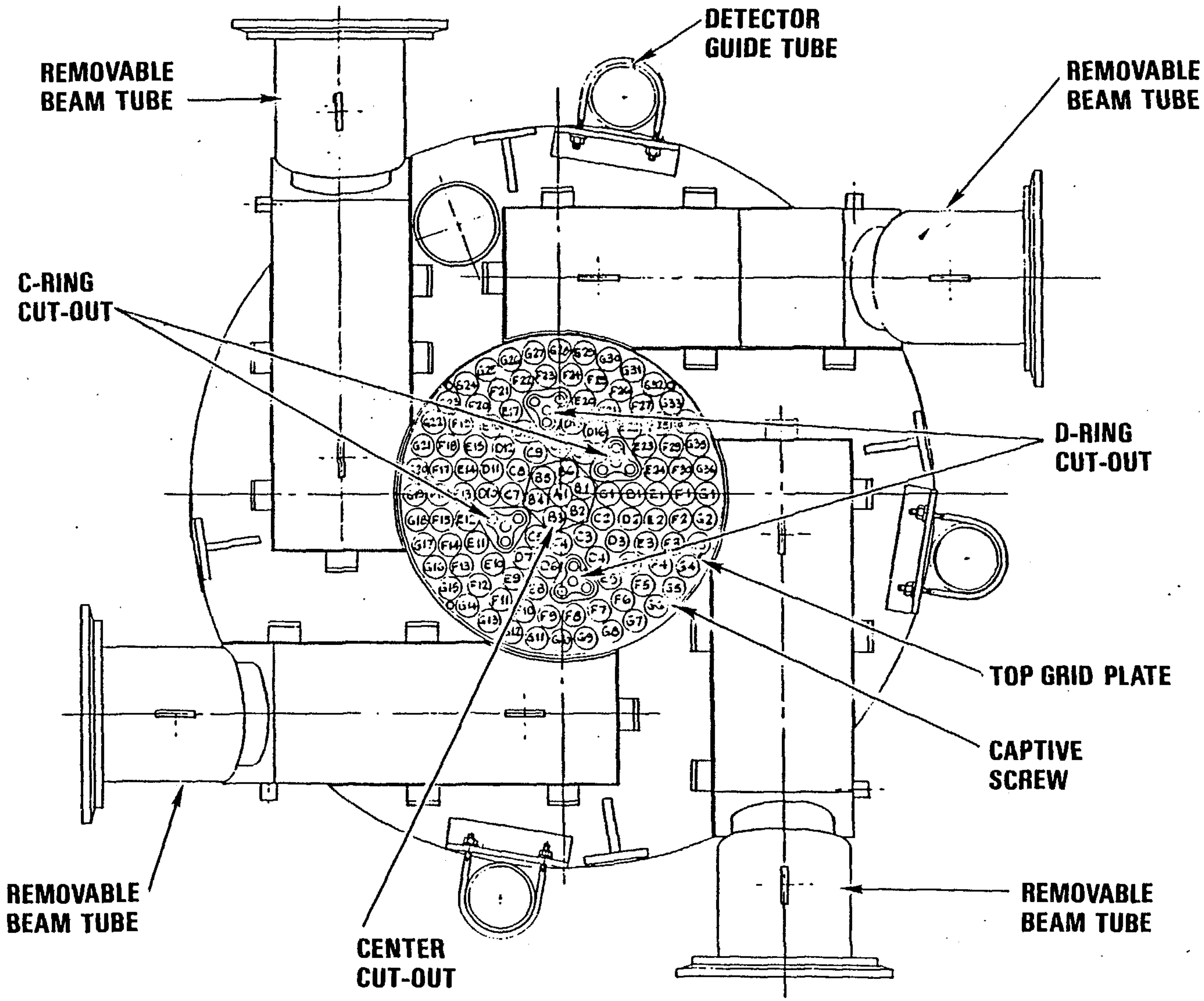


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Fig. 7

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# BEAM TUBE ASSEMBLY



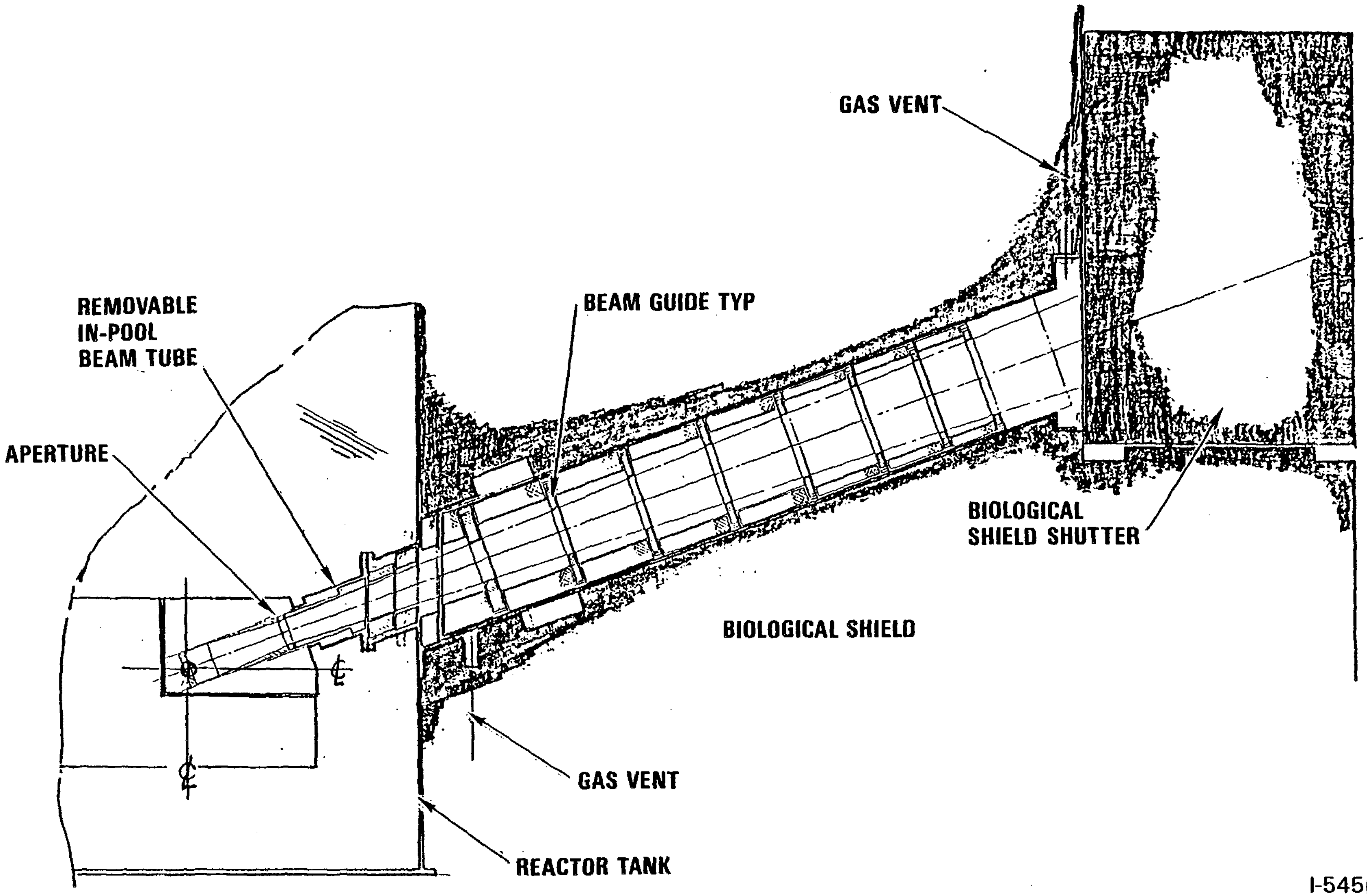


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Fig. 8

# COMPONENT POSITIONER

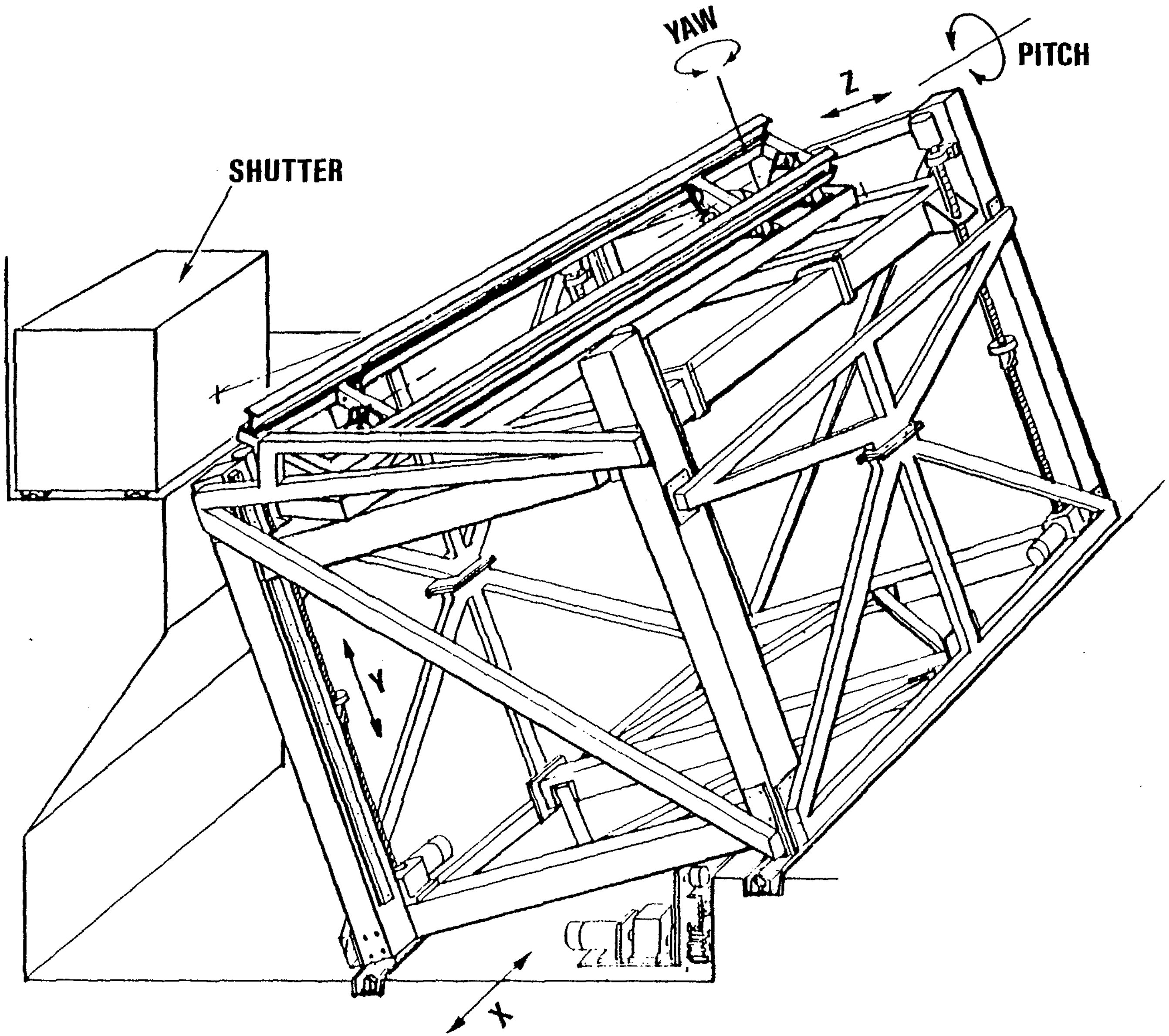


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Fig. 9

# SECTION OF 1/48 SCALE MODEL TELESCOPING NIS ARM



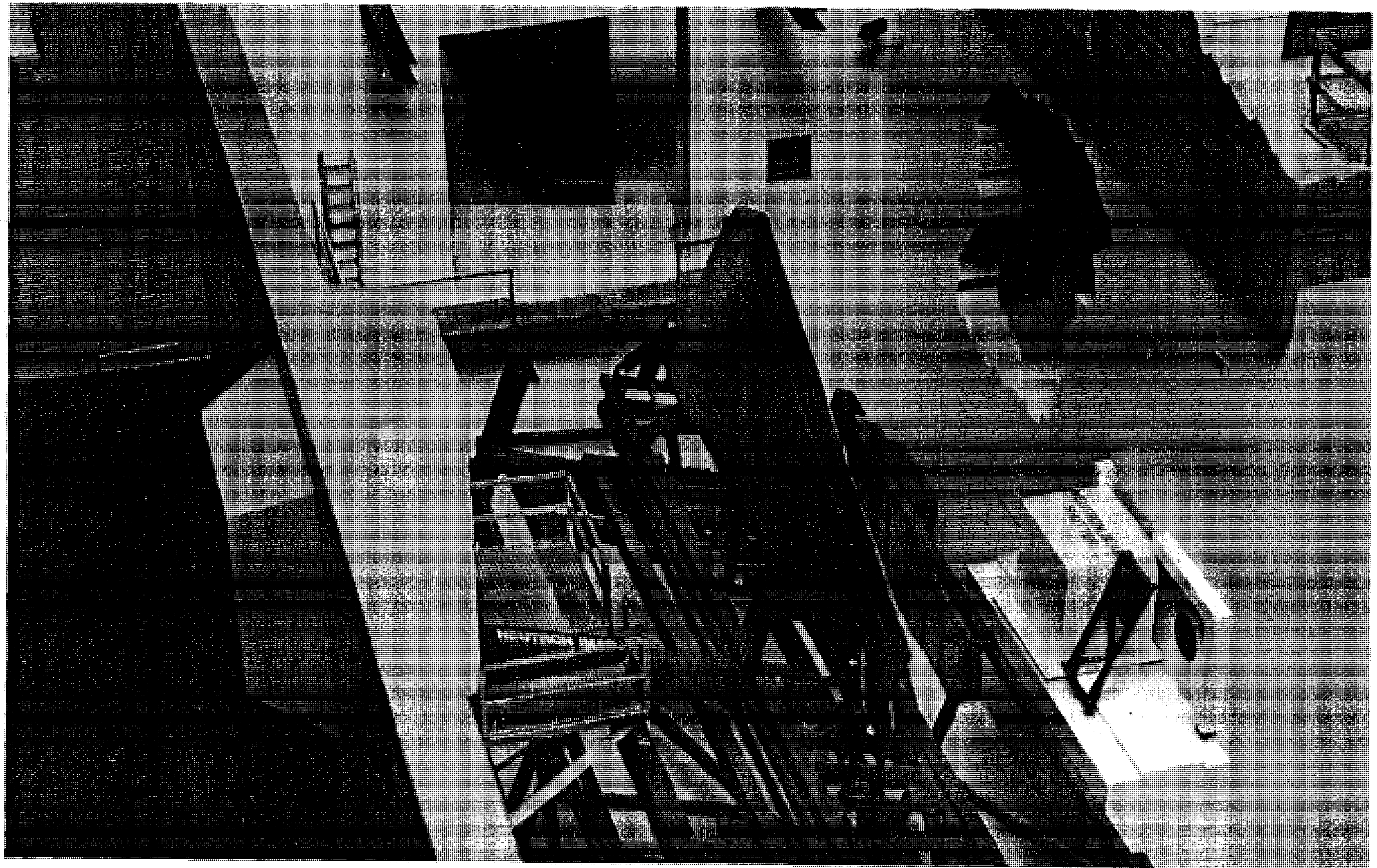

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Fig. 10

# INSPECTION SYSTEM CONTROL CONSOLE



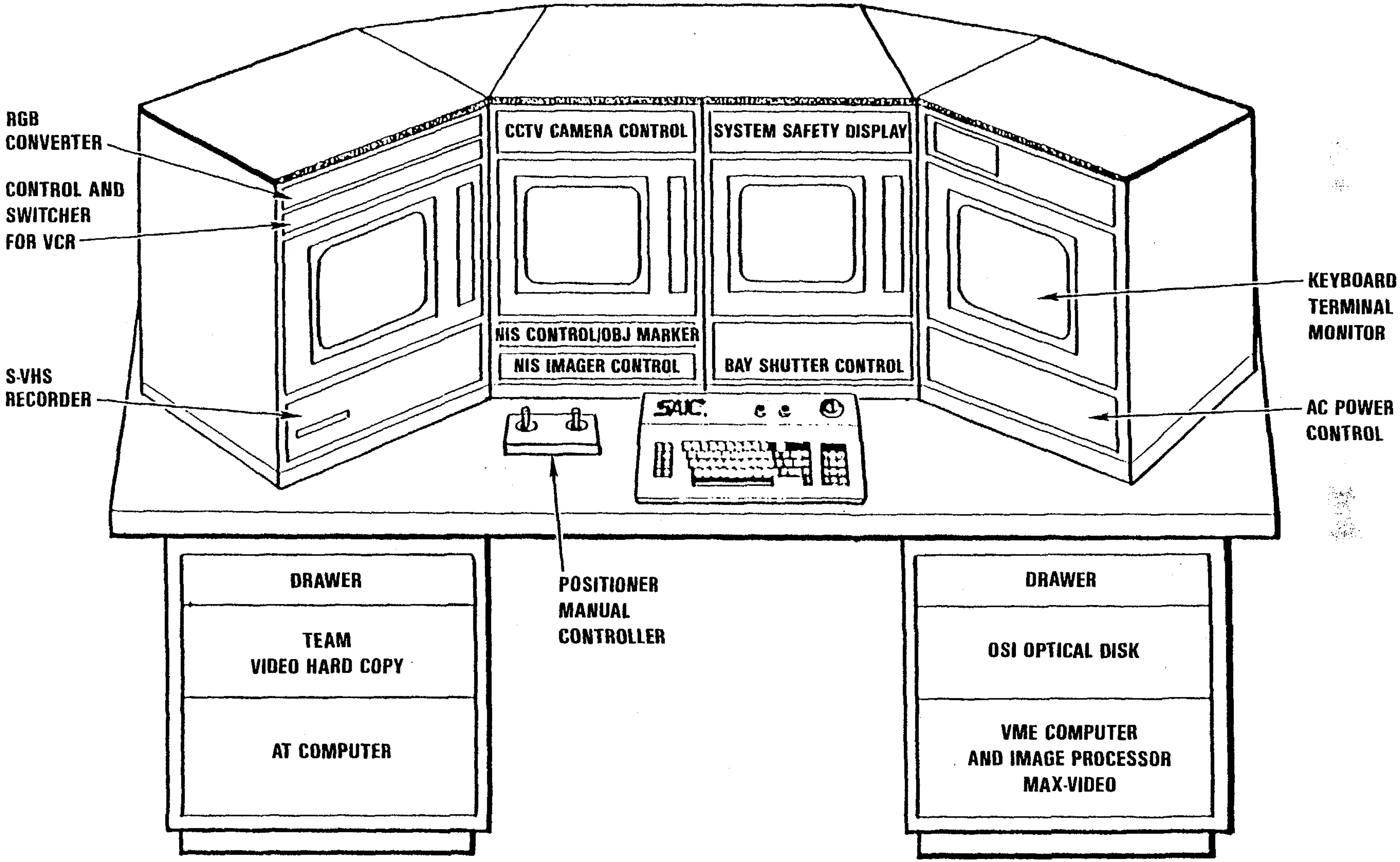


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Fig. 11

# SNRS CONSTRUCTION SITE

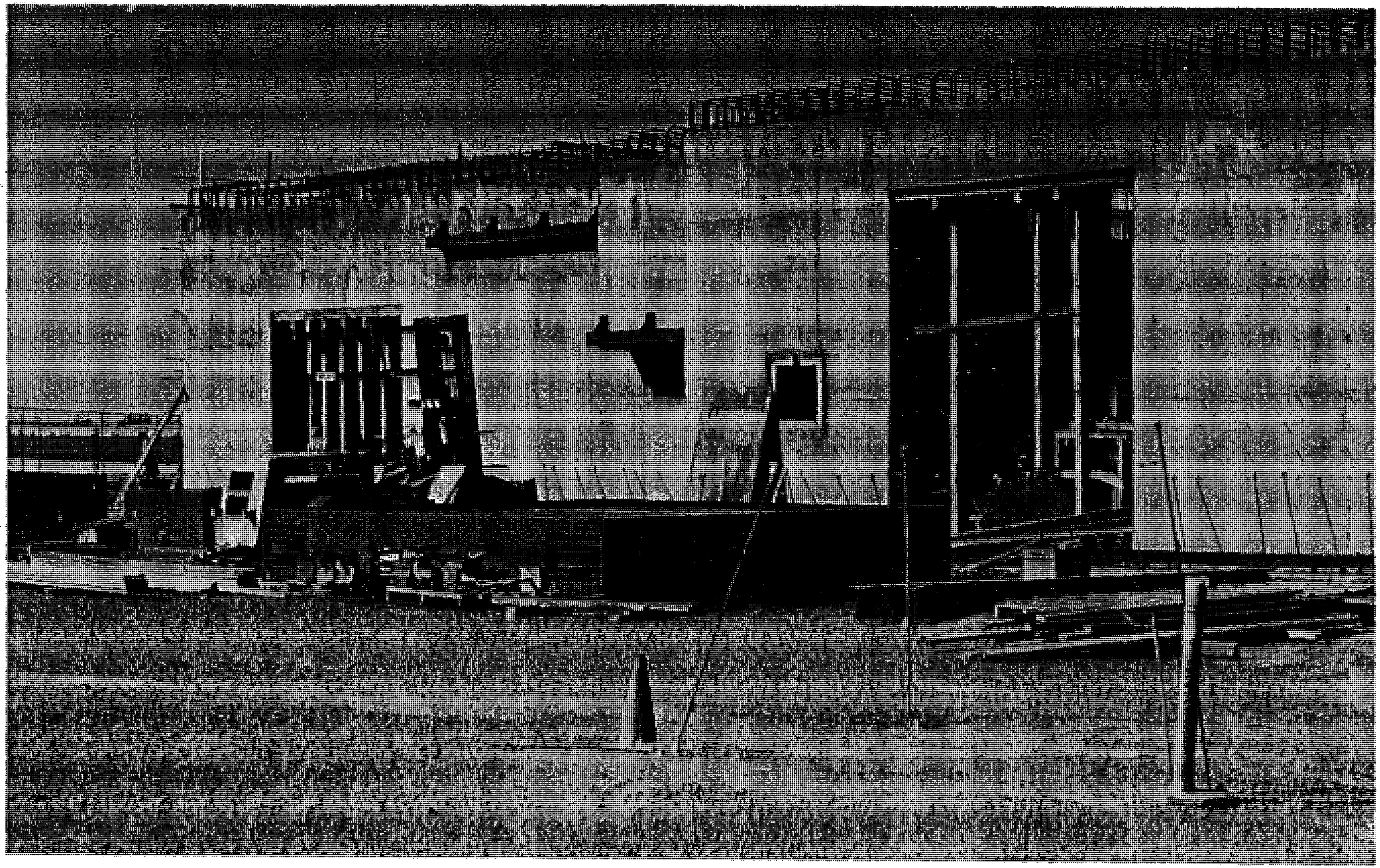

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Fig. 12