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POTENTIAL BIO-MEDICAL APPLICATIONS

OF SATURN NONDESTRUCTIVE TEST

METHODS

Robert L. Brown
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POTENTIAL BIO-MEDICAL APPLICATIONS OF SATURN NONDESTRUCTIVE TEST METHODS

ABSTRACT

A brief description of the history and purpose of nondestructive tests is followed by a short discussion of the following five new developments in nondestructive test methods.

a. A solid state radiographic image amplifier to replace X-ray film where permanent records are not required.

b. A new, low-level input closed-circuit television system, which includes image integration over long periods and contrast enhancement, intended for direct viewing neutron radiographic use.

c. A new, compact ultrasonic system, undergoing development for portable use (six inches in diameter and six inches long), and containing both scanning and pictorial readout devices.

d. A few applications of liquid crystals which are compounds whose color changes at precisely known and controllable temperatures.

e. A highly sensitive eddy current metal locating device of simplified design for wounds.

I. INTRODUCTION: NONDESTRUCTIVE TESTING PHILOSOPHY

A century or so ago, an inveterate gambler asked a mathematician friend how to calculate the odds of throwing any given number on the faces of a pair of dice, and obtained the formula from the intrigued mathematician.

That answer, turned to another purpose, allows us to define the probability that a given mechanical system will function as planned. This has proven so important that a new engineering discipline, nondestructive testing, has developed from the start given by that formula.

The formula states that the probability of any event is determined by summing all probabilities leading to the event. If a mechanism has 10 parts, each 90 per cent reliable, the assembly is only 30 per cent reliable.

Applying this reasoning to a Saturn V launch (Figure 1) is a sobering exercise. On the pad, a space vehicle is perhaps the most complex mechanism in existence. In ground support and vehicle, over a million parts must function flawlessly to put the payload into orbit. Obviously, each part must have a reliability so high that descriptive figures are meaningless.

Attempts to reach this level of reliability have forced advances in every branch of engineering, and are straining every technique to the limit. The older ideas of "test to destruction, rebuild stronger" to improve is still perfectly valid, but too expensive where the newer nondestructive test concepts can be applied - which is <u>almost</u> everywhere.

Nondestructive tests are precisely what their name implies. They are tests, using any available means, to reach a diagnosis as to the fitness of a component or device to function as intended, but without compromising serviceability in the process. This is not a simple problem, since finding a suitable means is sometimes difficult, as the "means" may not yet exist. So we develop "means," if we can.

Nondestructive testing draws on all areas of science and adopts whatever it finds useful. It uses all types of energy from the single thump of dynamite, through sonics to ultrasonics, radio frequency up to light, ultraviolet to X-rays - on occasion, even cosmic rays are used. Cosmic ray counters are clicking away in the pyramids of Egypt in a search for unknown chambers in unique nondestructive testing programs. Cosmic rays going through any hollow spaces will, by counting and computer analysis, reveal their location.

Recently developed equipment and methods for nondestructive testing of engineering structures (Figure 2) would seem to be equally applicable to testing for biological purposes (Figure 3) since the techniques, tools, and results required are similar.

II. SOLID STATE RADIOGRAPHIC IMAGE AMPLIFIER

Radiography is, perhaps, the most useful tool in the Nondestructive Test Engineer's kit. The information obtained from radiographs is well worth an average cost over twenty dollars a shot; but when tens of thousands of radiographs are made at that price on a single project, the cost factor has to be considered.

This kind of evaluation has high lighted the desirability of eliminating direct film radiography wherever possible.

Two years ago, a search was conducted of the literature in an effort to discover better and less expensive X-ray imaging means. This search uncovered a number of references to an obscure device, a "Solid State Image Amplifier," at that time in a laboratory stage of development. The device is similar in general appearance to a fluorescent screen, but converts input radiation into electric current, amplifies, and excites an electroluminescent material to form an output image, within the panel. The panel's outside power may be either alternating or direct current at quite low voltages and low power. Many designs, some of treme complexity, have been built in an effort to approach high sensitivity, high resolution, and long image storage. An engineering study, "Nondestructive Testing for Space Application," conducted by Marshall Space Flight Center, indicated problems of film development and storage in the space environment for the optimum NDT method of radiography. To solve the film problems a contract was issued to develop the solid state imaging system, with image retention capabilities, as a direct film replacement.

The phase A effort to develop a Radiographic Solid State Image Amplifier is complete with the delivery of an 8-inch by 10-inch image amplifier (Figure 4). This panel, the result of a decision to concentrate the effort on developing the simplest possible panel construction, is inherently easy to manufacture, and so has many advantages over more complex devices.

Two noteworthy developments, a means of producing a fine-grain, high trast, high sensitivity image panel, and a method of building panels into an amplifier having image retention properties previously considered unattainable, made it possible to meet or exceed all design objectives. Other in-house uses are now being explored for the image amplifier.

It is felt that the medical profession, as well as the nondestructive testing professions, will be potential users of this device.

The present imaging system requires no dark adaptation and is quite sensitive; it is possible to get optimum results in radiography of the hand with ~~40~~ 35 kilovolts and ~~10~~ 5 milliamperes. The image quality is superior to fluoroscopy in every aspect.

Work is continuing with the phase B contract, now under way, which is expected to produce similar results with less than a milliampere input in the panels being developed. This sensitivity will match that of the image intensif :s now being used for direct viewing 'n medicine, but better resolution in a simpler device will be available. The image amplifier shown can resolve a 3 per cent density change. This contrast sensitivity is easily reached by varying the panel's power supply voltage, which optimizes the panel's response to the input radiation level. A test photograph (Figure 5) demonstrates the high image quality possible.

When the panel is exposed to X-rays, an image is developed, much brighter than, but similar to, a fluoroscope image. The image remains visible as long as conditions are unchanged. The image disappears within seconds when the power is cut. A single panel can be reused many times within its radiation lifetime of 100 hours or more. A minor disadvantage for some medical purposes is the panel reaction to motion. There is a time delay of approximately one second for image fading and reforming during motion. Thus, the panel cannot be used at present fo .n-motion studies except in the case of very slowly moving objects.

We have another version of the image amplifier under development. Feasibility of an alternate version utilizing an image retaining panel has been demonstrated. This second panel can be regarded as a reusable photographic plate to be exposed then studied at leisure. Erasure and re-exposure may be performed as desired. Image development is within seconds, and an excellent image can be held for over ten minutes, with only mild degradation after fifteen minutes of retention. Both versions of solid state panels photograph easily as shown in Figures 6 and 7, which illustrate the non-storage panel image and an image retained for fifteen minutes, respectively.

The small amounts of X-ray exposure necessary for suitable images would make it feasible to increase the use of X-ray in general patient diagnosis. It is apparent that the study of the chest pathology would be enhanced by the clearer resolution and the improved detail available, as contrasted to other direct viewing vices. The low price (expected to be less than 1000 dollars for the system) and great simplicity of the device should be of great value in reducing costs. Using presently available isotope sources, it may be possible to radiograph under circumstances impossible with presently a ailable X-ray systems, such as on-the-spot at automobile accidents. Figure 8 shows such a system; it is completely portable, can be carried in an attache case, and weighs slightly under thirty pounds.

III. OTHER IMAGING TECHNIQUES

A. Neutron Radiography

1. Neutrons have recently entered the NDT tool kit because of the unique behavior of a collimated beam of neutrons. Such a beam penetrates most materials easily. With neutrons, radiography through ten inches of lead is commonplace. The opacity of the elements to neutrons varies randomly, with a few, including hydrogen, boron, cadmium, and some of the rare earths, much more opaque t n the rest. The hydrogen content of organics makes them easily radiographed, even through astonishing thicknesses of the usual structural metals.

2. This unique behavior of neutrons, properly applied, makes neutron radiography presentlv, and potentially, of great value. Imaging techniques presently available for neutron radiography leave much to be desired. The available neutron sources include generators, atomic piles, and isotope sources. Our study concluded that generators (such as the Van de Graaff type) were the best choice as sources for neutron radiography, and closed circuit television was the best imaging system. Thus, a closed circuit television system (Figure 9) is being designed around an imaging system which operates with the low neutron radiation level of a generator. The system may be adapted "as is" to experimental laboratories where neutron radiography is utilized. The ability to form images with very low

neutron levels might merit a closer look for potential medical use of this unique iiation with its capability of radiographing the tissues.

3. The image converting device is a scintillating screen, which produces a pulse of light with each neutron intercepted, but which has low ability to sense gamma radiation. The image on the scintillator is viewed by a remotely controlled television camera using a recently developed "Secondary Electron Cathode" vidicon camera tube, assisted by a mating magnetic focus image amplifier tube. The combination of sensitivity, high resolution, faithful gray level rendition, and the ability to integrate incoming light over long periods to produce images, are unique characteristics of these new tubes. We hope to use very low levels of neutron flux to produce high quality images with this system.

4. The camera scan rate may be changed at the operator's discretion, with the last image scanned being repeated by a memory system, which holds for long storage times. A new image contrast enhancement system in the amplifier chain i under control of the operator. Shades lighter or darker than operator selected limits will be electronically eliminated, and the selected band of gray levels left will be enhanced to cover the range from white to black. This should allow much greater contrast sensitivity to this system than is available to users of standard closed circuit television and is closely analogous to the results achieved by digital computer contrast enhancement, which involves more complex techniques.

5. The value of this high-sensitivity, enhanced-contrast system in aiding Orthopedic Surgery, Cardiac Catheterization, and any other surgery requiring extremely high contrast media in the patient is apparent. The system's ability to be used in "in-motion" studies, as well as its ability to detect very low levels of tracers such as chromium compounds should be quite valuable if these design principles were applied to X-ray telev ion systems.

B. Ultrasonic Systems

1. A typical ultrasonic inspection system is shown in Figure 10. This system records a pictorial type scan, a typical pattern being shown in Figure 11, which is a record of inspection of a test panel selected from our files. White areas indicate no signal, intermediate areas indicate some return, and dark areas full return. A good panel would show no white areas. The ultrasonic sound imaging systems are receiving much attention, due to straightforward ease of use, safety, and highly dependable results.

2. A new device under development ~~(shown in Figure 12)~~ is a small hand-held "gun" which contains a simple automatic scanning and readout system. The raster will cover a 3" circle, and will produce an image output with the same shaft that carries the crystal transducer. This is accomplished by "writing" on a solid state image amplifier with a point light source that is modulated by the returned ultrasonic signal. The conformal pad allows pressing of the device against a variety of body contours and provides efficient coupling for the ultrasonic search beam. Amplifiers, signal generators, and power are connected to the search/display unit by flexible cable. The device is designed for compactness, ease in interpretation, and simplified control systems.

3. The possible use of ultra-sound to give bone density studies would be useful in many areas. Determining fractures and the healing rate of fractures is an obvious use. More valuable, perhaps, would be the evaluation of changes in the bone density in osteoporosis, bone metastasis, and many other problems associated with calcium loss from the bone or calcium replenishment to the bone. If qualitative measurements could be made and quantitative measurements could be performed with accuracy, great benefit in the field of metabolic changes in the bone structure would be realized.

C. Liquid Crystals

"Liquid crystals," the cholesterol base temperature indicators, are becoming important also. These compounds undergo a reversible phase change during a very slight temperature change (the more sensitive in less than 0.1°k). The phase changes produce spectacular color changes in thin films of the liquid crystals, a most useful phenomenon. Additives to these compounds shift the temperature at which the phase change occurs so that a wide range of indicators centering around body temperature can be produced. Figure 13 is a typical aerospace use. The panel has adhesively bonded internal spacing material with built-in unbonded flaws. The panel is heated by a bank of lamps and, since unbonded areas do not conduct heat away as fast as well bonded areas, the phase/color change indicates the defective areas quite well. We are evaluating the use of film which has the liquid crystal sandwiched between thin plastic sheets; or alternately, a cloth coated with microscopically small plastic capsules filled with liquid crystals. These reduce the messy business of application and allows us to use liquid crystals with much greater convenience than formerly. Liquid crystals of high sensitivity ~~could be~~ are useful in detecting very minor differences in skin temperatures in cases of embolism, abscess, intra-abdominal infection, and, perhaps, would even be useful in detecting abscesses within the liver or within the kidneys. Liquid crystal temperature indicating clothes have obvious uses in dynamic studies of body temperature changes.

IV. EDDY CURRENT THICKNESS GAUGE

Figure 14 is of a thickness gauge, developed to measure the spray-on foam insulation (SOFI) used on the Saturn V second stage. The foam is backed by the aluminum vehicle skin which suggested that an eddy current device, developed earlier at Marshall Space Flight Center for another purpose, could be adapted to measure the foam thickness.

This earlier device was an oscillator, designed to sense metal within inductive field. The adaptation was quite successful, the latest versions of the proximity gauge being able to directly measure out to 14 inches. In contrast to previous eddy current devices, this gauge has very low sensitivity to the body, is highly sensitive to metal, is extremely simple, and is easy to use. This suggests that the thickness gauge should have value in searching wounds for metal fragments, as many dangerous shrapnel wounds appear to be merely scratches when viewed without access to X-ray equipment.

Bullet wounds, if shallow, are far less dangerous than deep penetrations. These conditions are easily detected with the thickness gauge. This would be of value in assessing criticality of such injuries.

This random sampling of techniques and devices developed by NASA/Marshall Space Flight Center is a portion of our contribution to better nondestructive test methods. We hope that some of these may be of value in your area of medicine.

POTENTIAL BIO-MEDICAL APPLICATIONS
OF SATURN NONDESTRUCTIVE TEST METHODS

LIST OF ILLUSTRATIONS

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FIGURE 2 - X-ray Inspection Station, Aerospace Components

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FIGURE 4 - Solid State Radiographic Image Amplifier System

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FIGURE 6 - Television Resolution Pattern, Direct Exposure

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FIGURE 8 - Radioisotope - Image Amplifier Inspection System

FIGURE 9 - Schematic, Neutron Facility Using Low Level Source

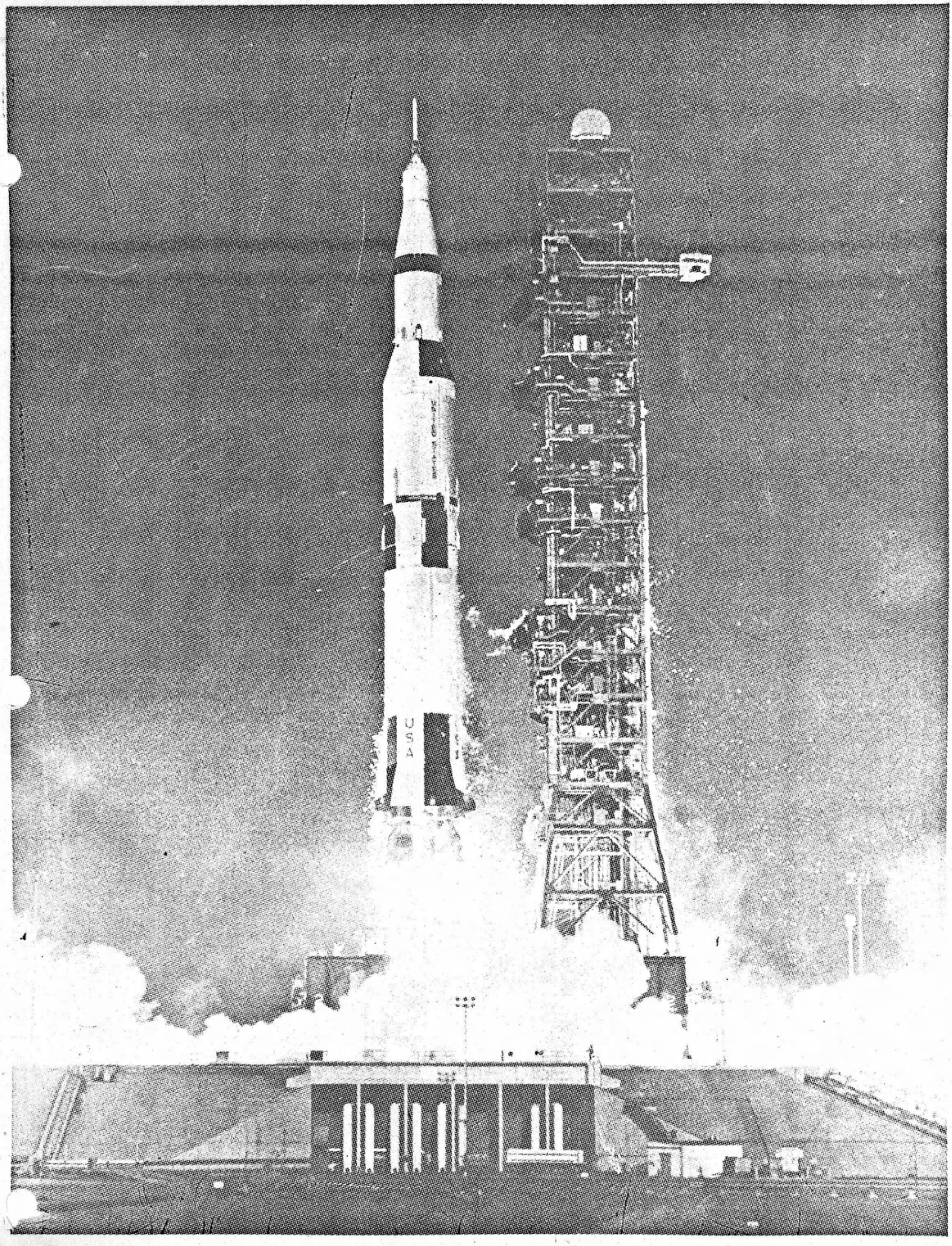
FIGURE 10 - Automatic Ultrasonic Scanning Device

FIGURE 11 - C-scan Record of Ultrasonic Inspection

FIGURE 12 - Hand-Held Ultrasonic Scanner

FIGURE 13 - Liquid Crystal Inspection of Adhesively Bonded Panel

FIGURE 14 - Eddy-Current Thickness Gauge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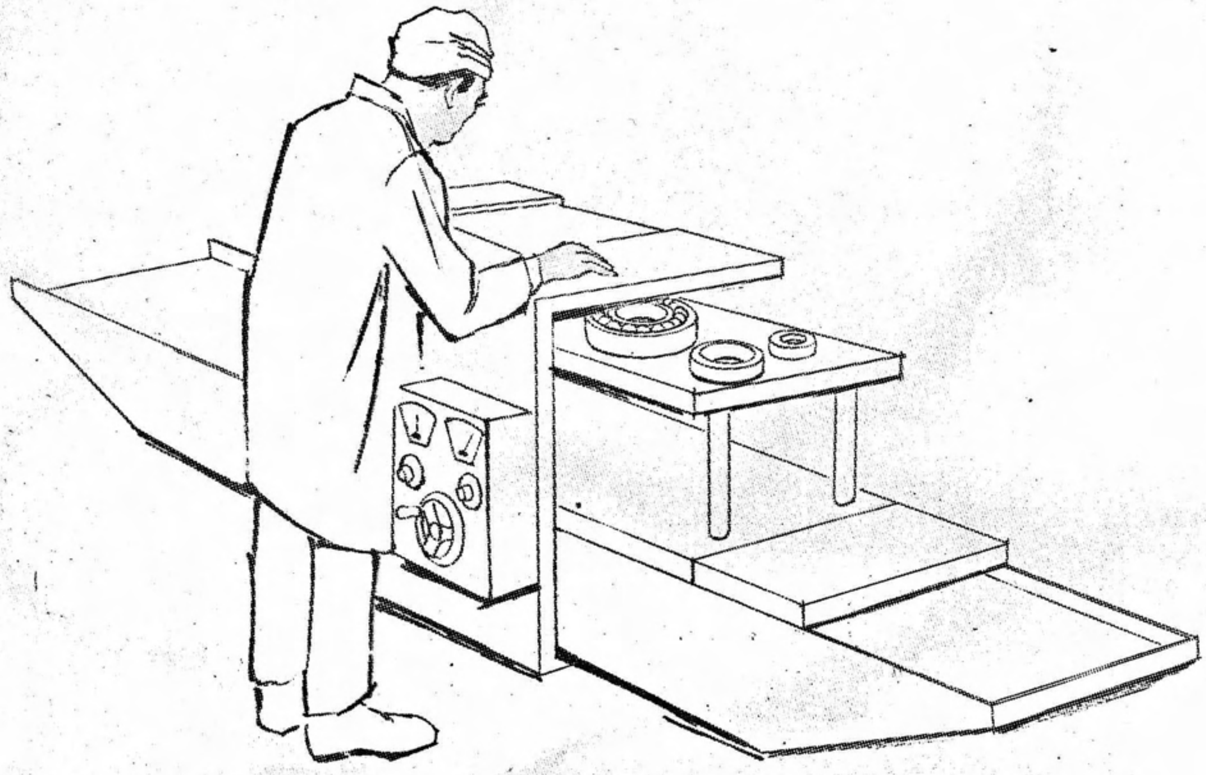
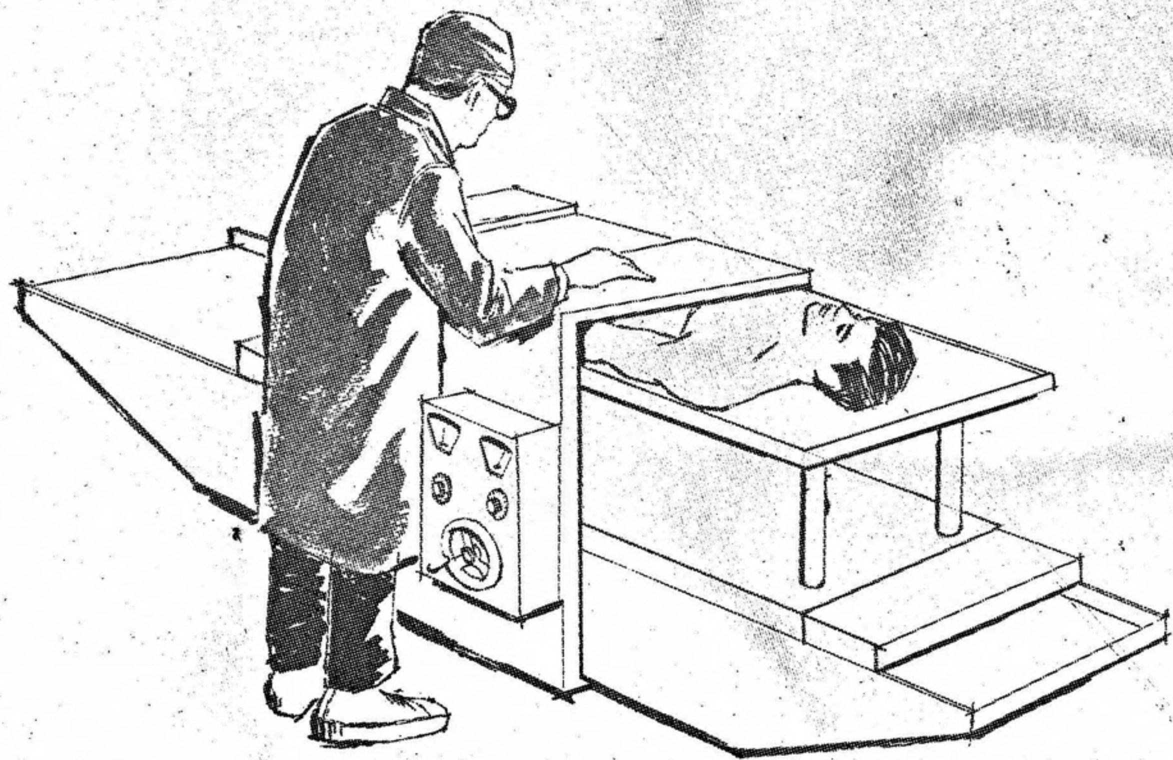
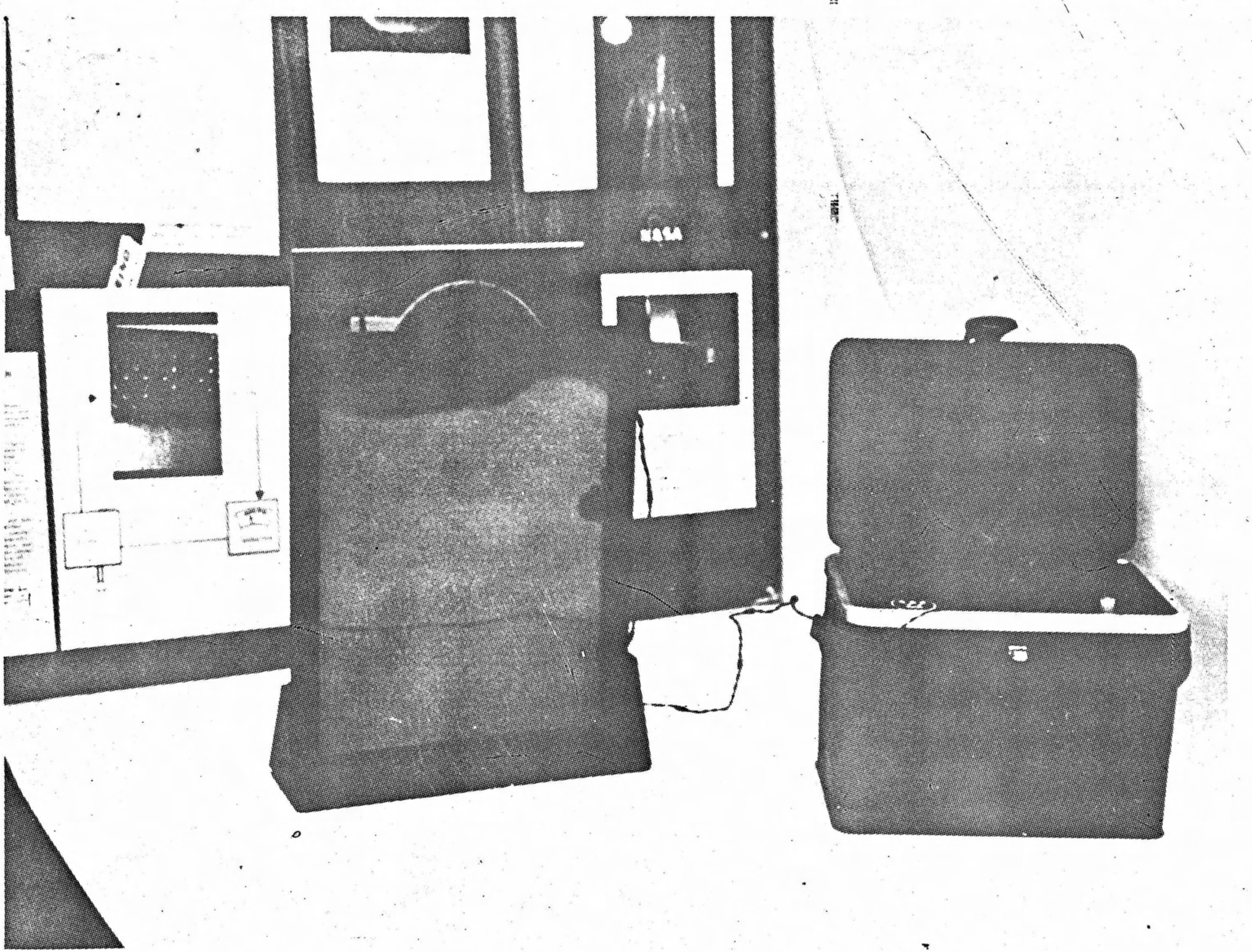


Production Line X-Ray Inspection Table



Solid State Radiographic Image Amplifier Examination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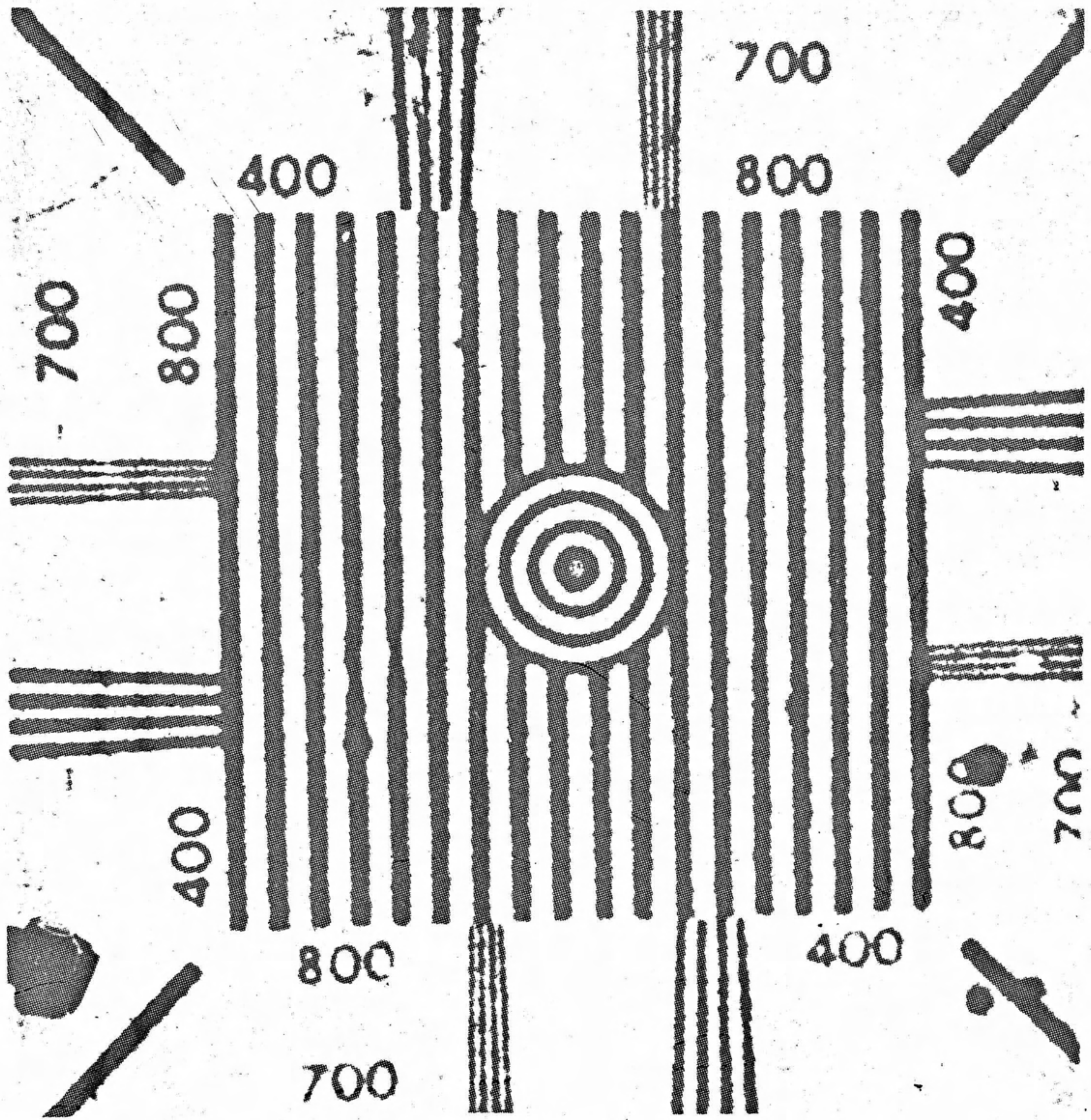
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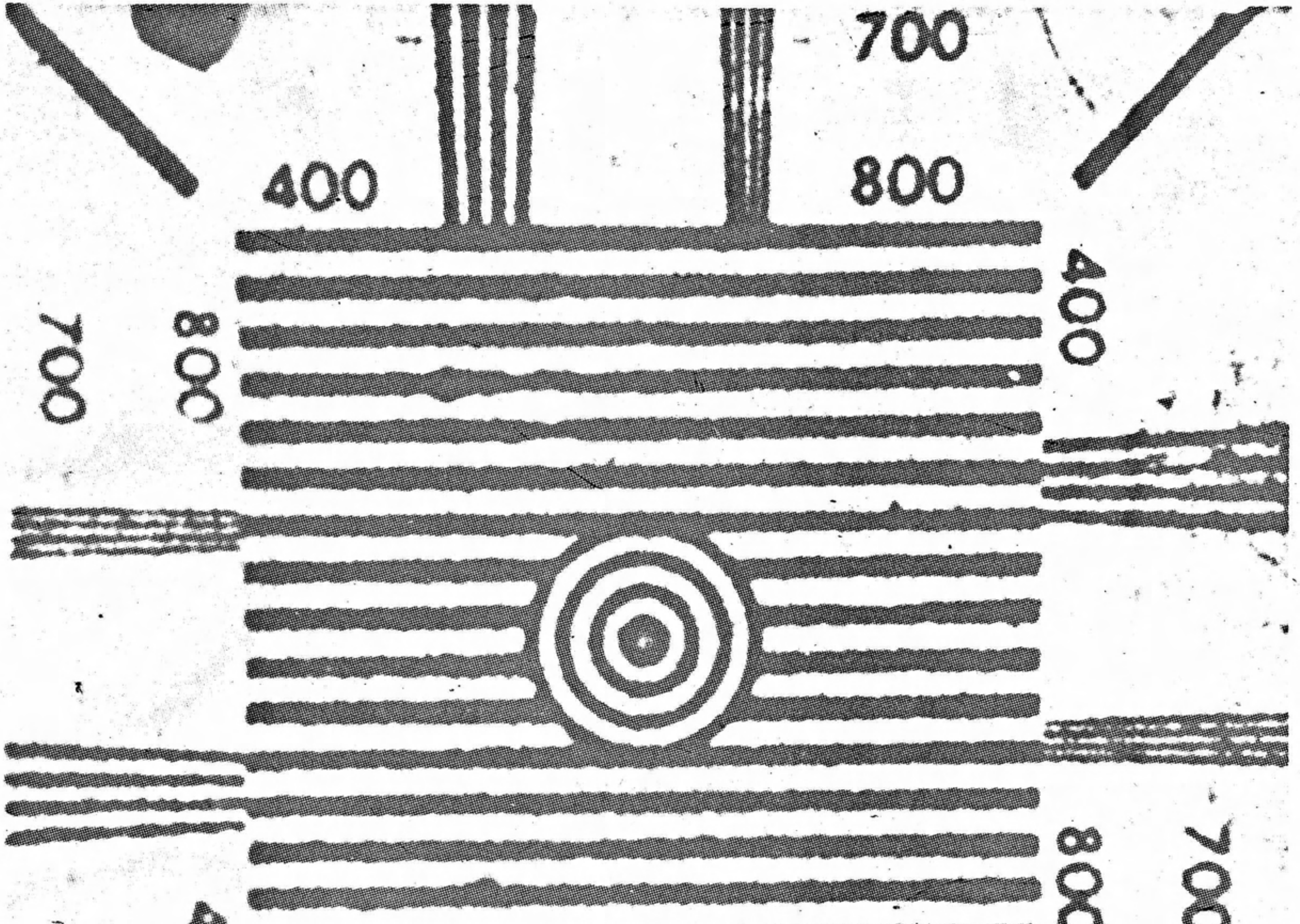
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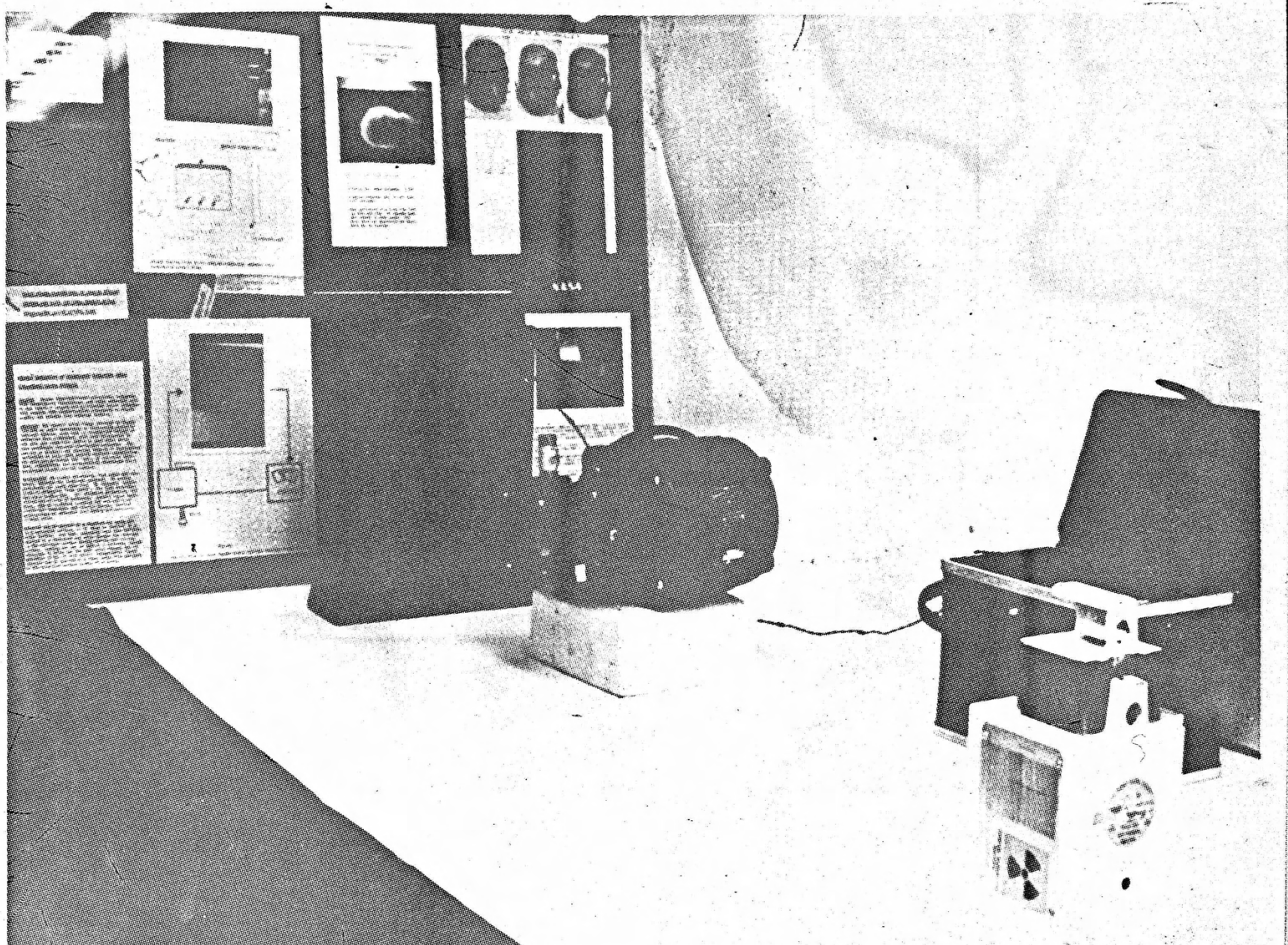
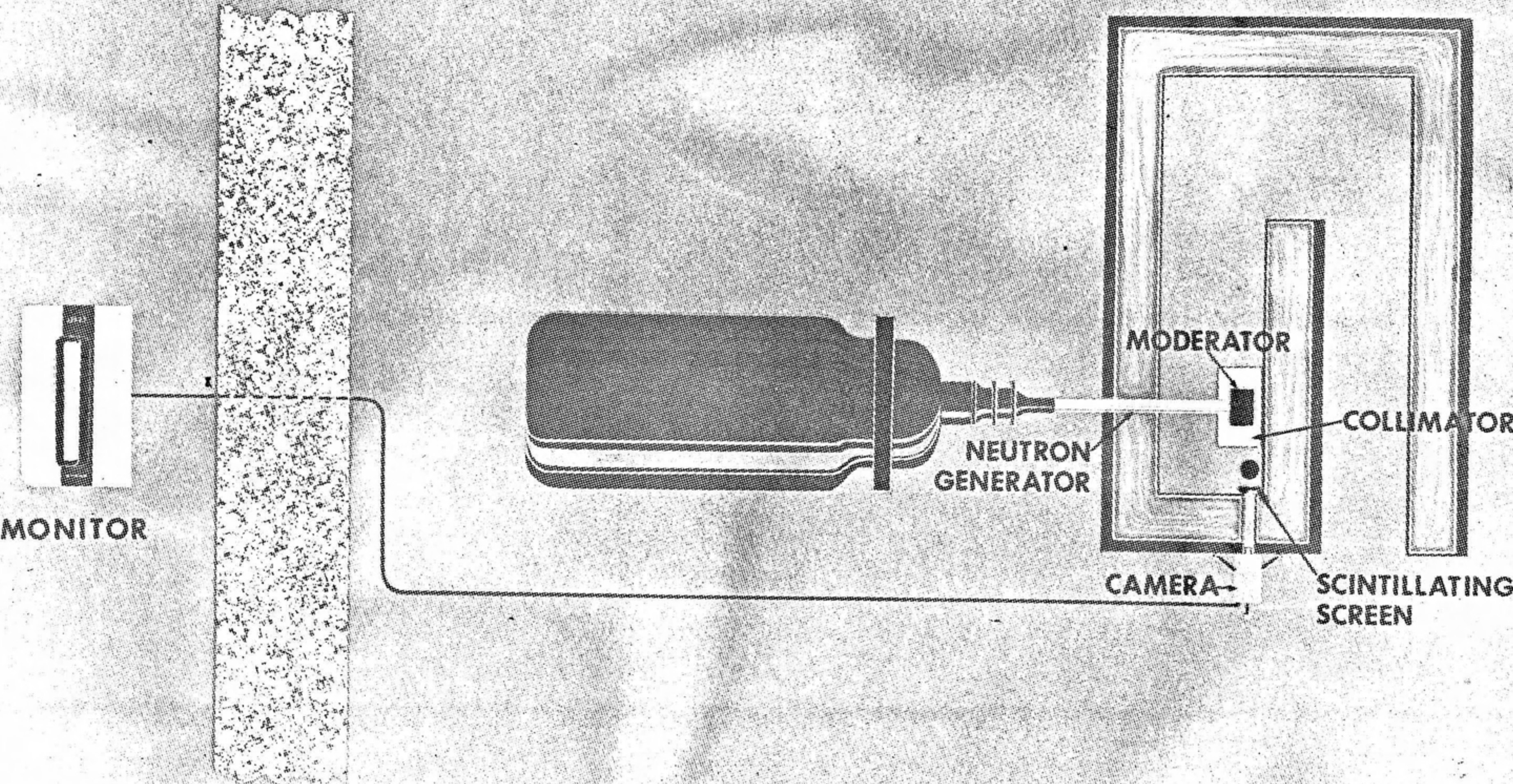
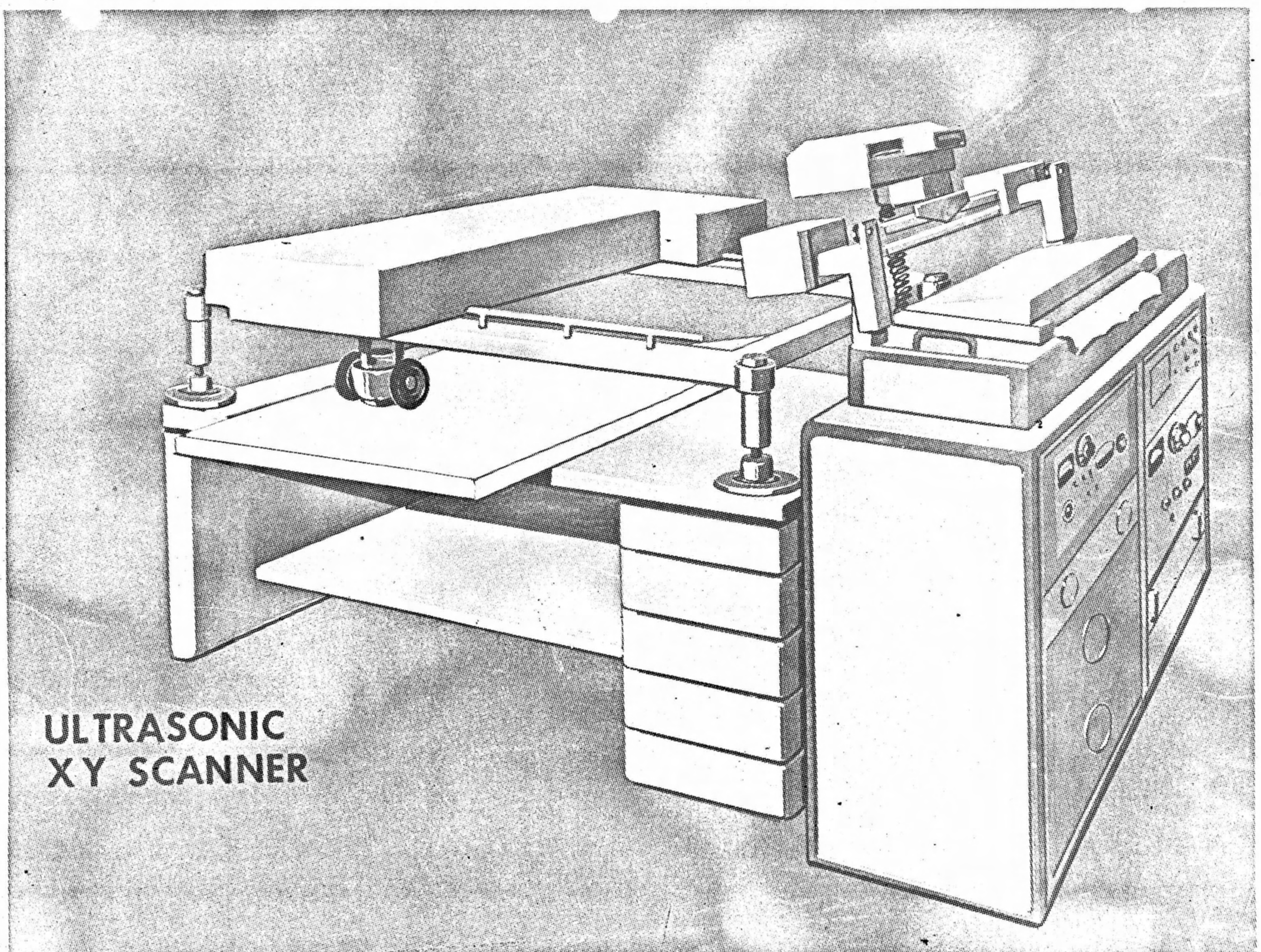
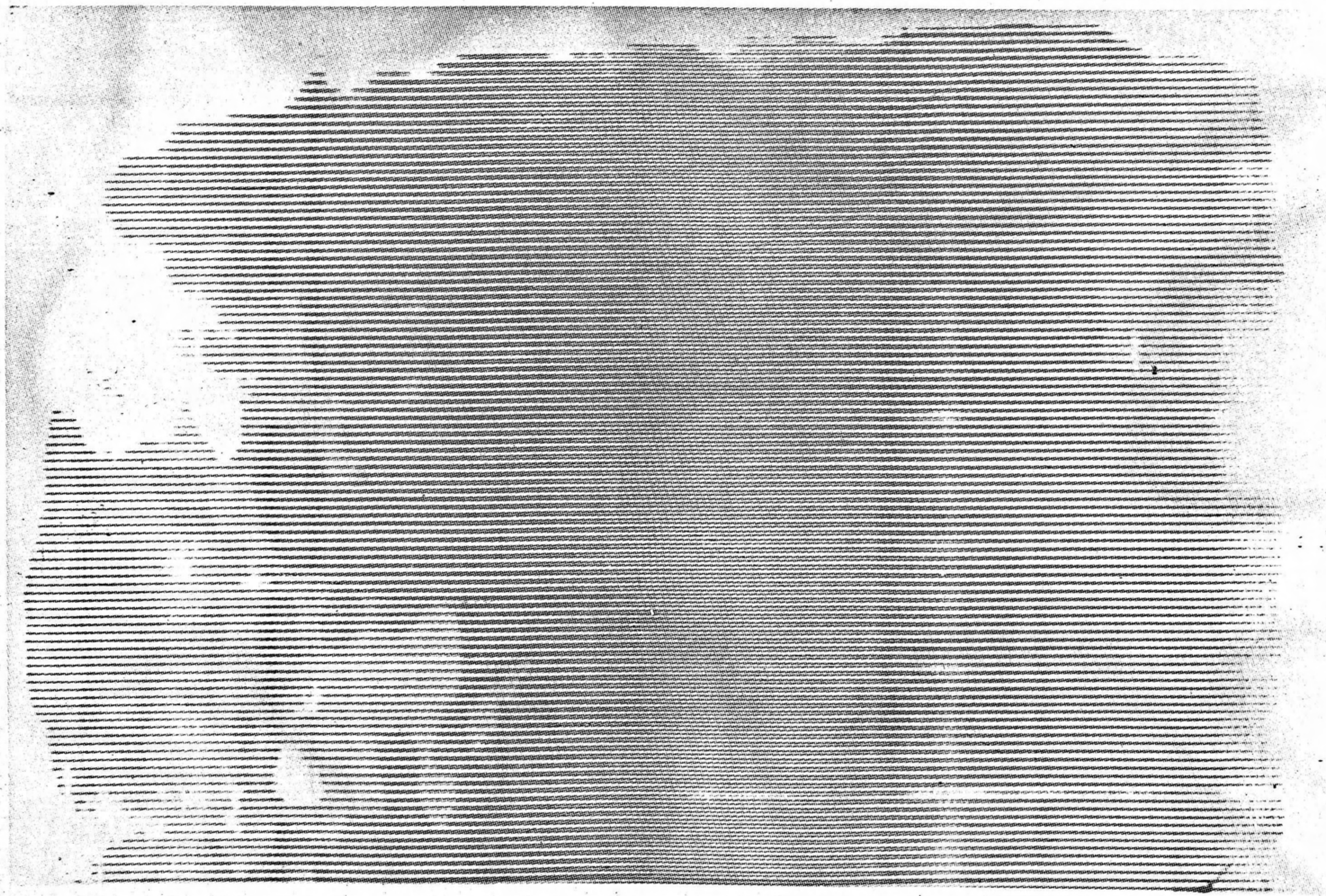


VANde GRAAFF ACCELERATOR





ULTRASONIC
XY SCANNER



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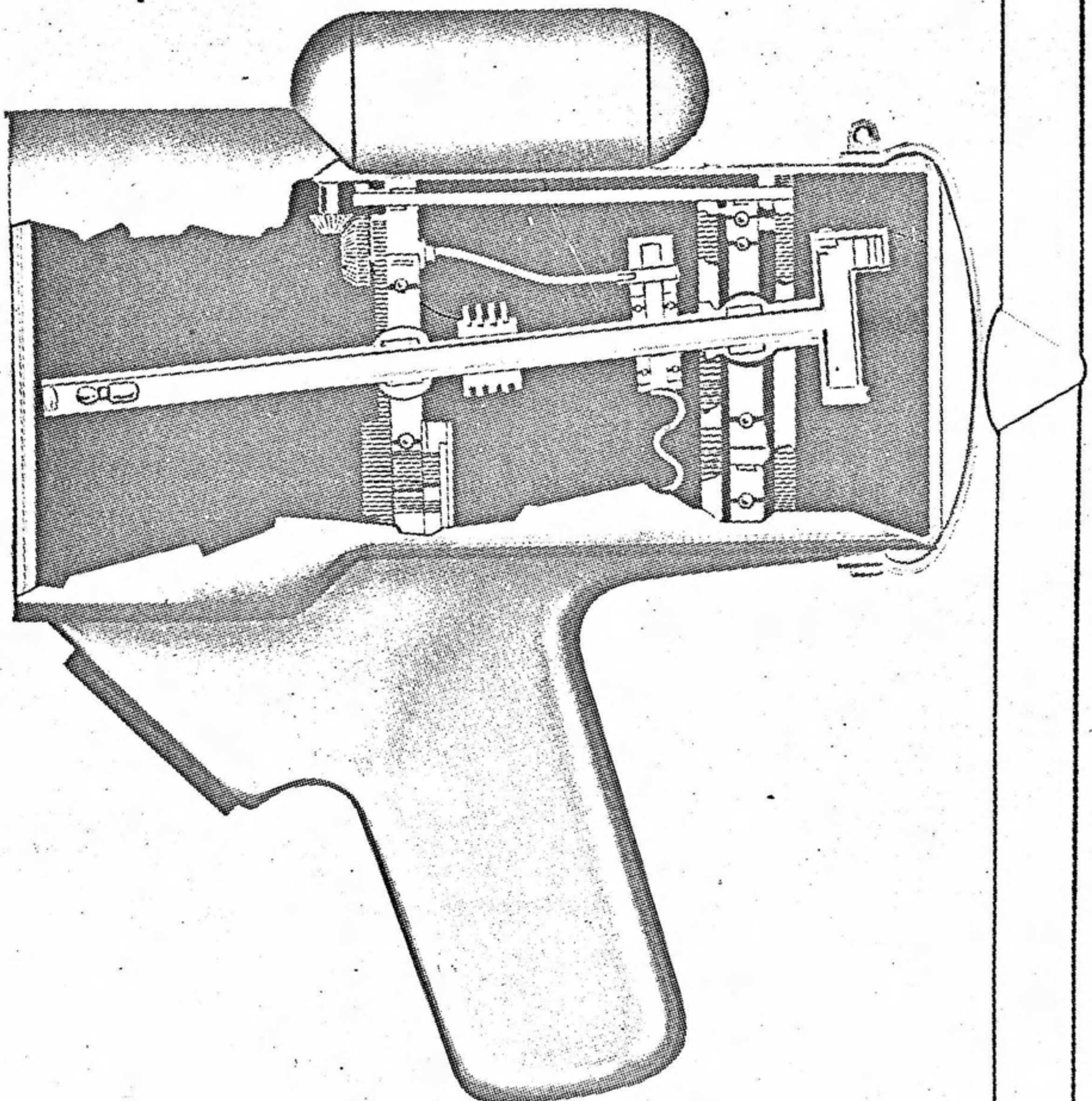

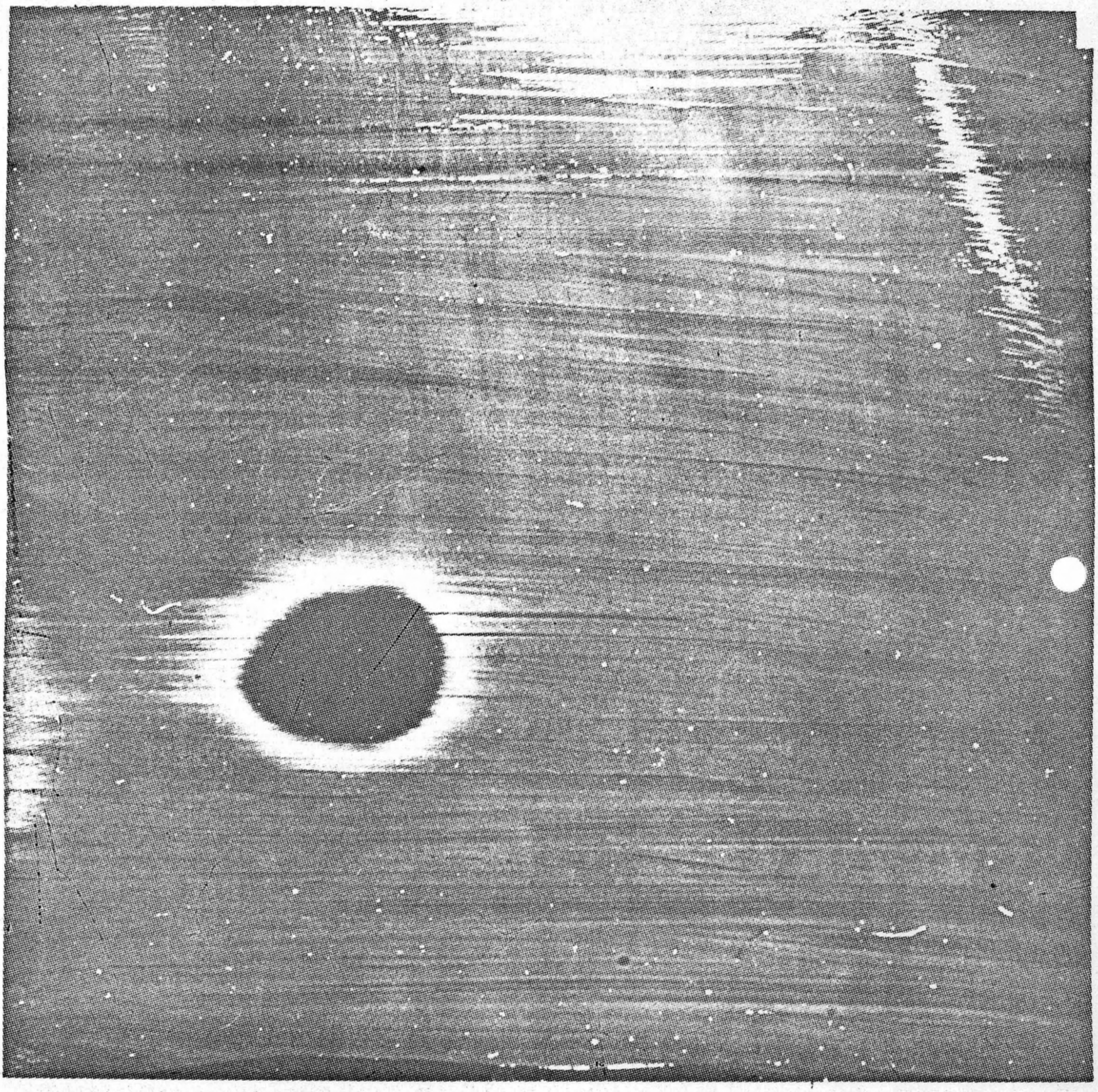

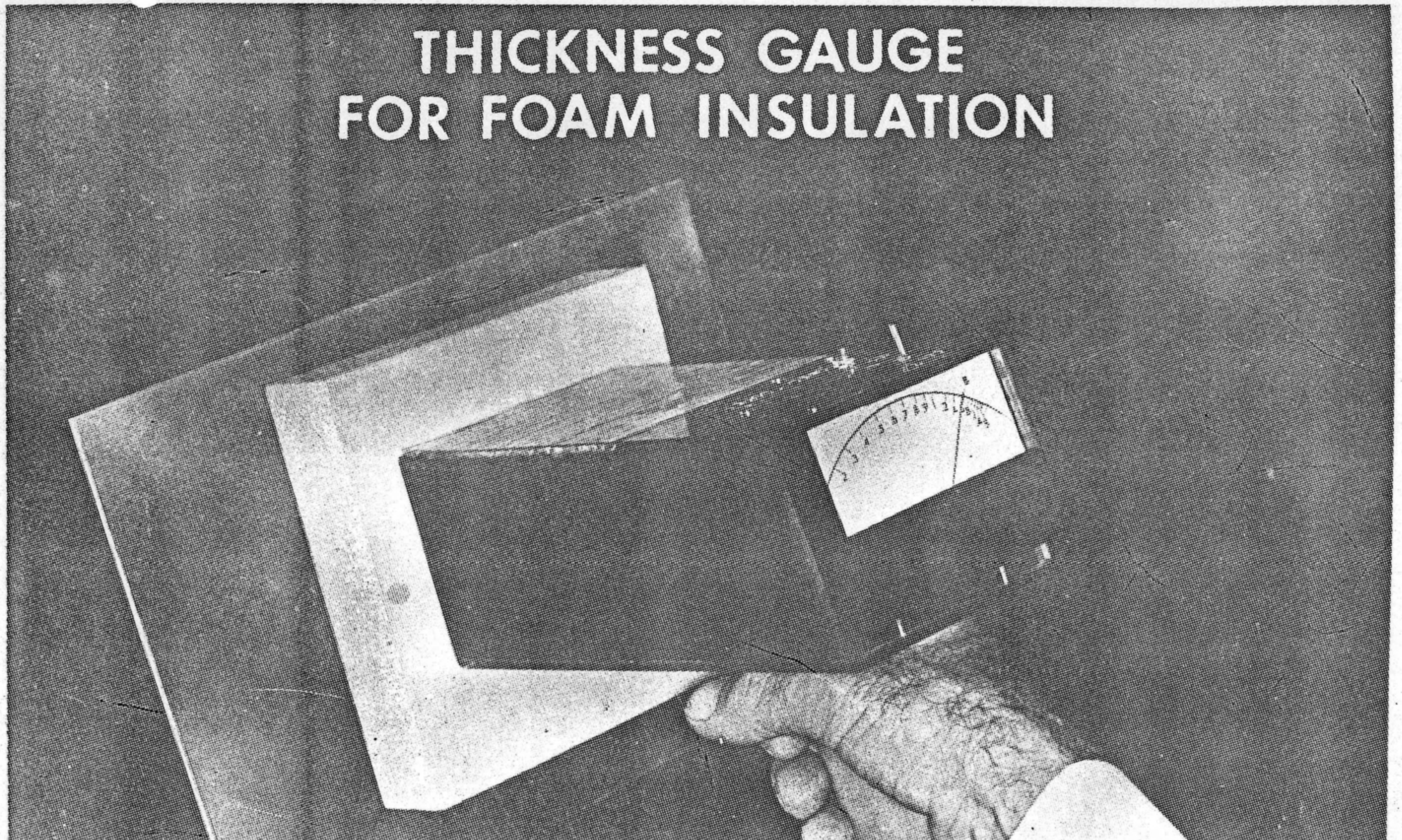
THICKNESS GAUGE
FOR FOAM INSULATION
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obtained in a typical radiographic scene. Light radiation was used in this test. The table below shows some of the results of this test.

Horizontal Width, inches	Photocathode Light Level, ft-cdl	Maximum Resolution, inches
4	1.25×10^{-4}	0.008
2	5×10^{-5}	0.010
2	1×10^{-4}	0.007
2	2.5×10^{-5}	0.007 (1)
2	2.5×10^{-6}	0.007 (2)

The first three tests were made at standard 30 frame/sec 2 to 1 interlace conditions. The fourth test was made with a single field readout with an integration rate of 3.2 seconds per readout, and the fifth test was made with integration times of 10 seconds. Note that the minimum target size was 0.007", and that superior resolutions might be expected when new target material is obtained. The target itself was a wire mesh which had equal size holes and wires. It was assumed that this mesh was producing a 100% contrast image.

During the report period, representatives of MVR Corporation demonstrated a portable disk recorder system. Specifications on this system include a 40 db signal to noise ratio and a bandwidth of 3.5 megahertz. This unit was utilized with the SEC vidicon in the standard scan mode, and it was noted that nine shades of gray were transmitted from the SEC vidicon through the final display; however, the horizontal resolution of the system dropped, predictably, from 550 lines to 350 lines. Some preliminary tests were made with this recorder on the long range integrating period, but results were not entirely satisfactory because an electrical trigger circuit from the camera to the recorder was lacking. However, horizontal resolutions of 350 lines and at least five shades of gray were obtained from the SEC vidicon-disk recorder combination at light levels in the approximate order of 10^{-7} foot-candles over integration periods of roughly 15 seconds. It is felt that these tests demonstrated the feasibility of the system, and only an optimization of parameters such as bandwidth and electronic triggering would be required to providing a fully satisfactory display.

Work is continuing on the video processing circuitry. Several circuits for level selection are under consideration.