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NEUTRON RADIOGRAPHIC

VIEWING SYSTEM

Final Report

CR-123802

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

George C. Marshall Space Flight Center

Huntsville, Alabama 35813

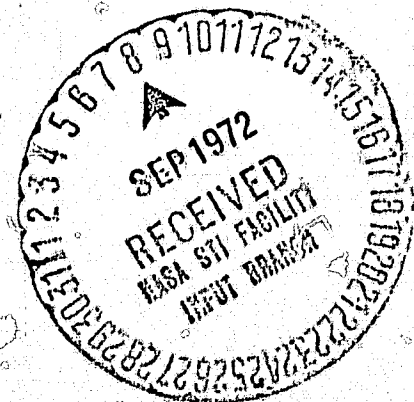
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Under Contract NAS8-30070

Zenith File No. 8661-FER

February 1972

Government Engineering Department
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ABSTRACT

This report describes the design, development and application of a neutron radiographic viewing system for use in nondestructive testing applications. The system basically consists of a SEC vidicon camera, neutron image intensifier system, disc recorder, and TV readout. Neutron bombardment of the subject is recorded by an image converter and passed through an optical system into the SEC vidicon. The vidicon output may be stored, or processed for visual readout.

All requirements for the system as defined by the Scope of Work have been met or exceeded in tests run thus far on the supplied equipment.

TABLE OF CONTENTS

Section		Page
I	INTRODUCTION	1-1
II	END ITEM DESCRIPTION	2-1
	2.1 Statement of the Problem	2-1
	2.2 Neutron Radiography	2-2
	2.2.1 The Neutron	2-4
	2.2.2 The Neutron Radiograph	2-6
	2.3 System Considerations	2-8
	2.3.1 Neutron Conversion	2-11
	2.3.2 Light Coupling	2-11
	2.3.3 Image Converter	2-14
	2.3.4 Pickup Device	2-22
	2.3.5 Storage	2-30
	2.4 System Description	2-30
	2.4.1 Neutron Image Intensifier	2-34
	2.4.2 Secondary Electron Conduction (SEC) Vidicon Camera	2-34
	2.4.3 Control Circuits	2-35
	2.4.4 Disc Recorder	2-35
	2.4.5 Video Processor	2-35
	2.5 System Specifications	2-36
	2.5.1 GFE and Purchased Equipment Specifications	2-37
	2.6 System Operation	2-40
	2.6.1 General	2-40
	2.6.2 Neutron Image Intensifier	2-40
	2.6.3 Control System	2-42
	2.6.4 Video Processor	2-47
	2.6.5 SEC Vidicon Camera	2-52
	2.6.6 Video Disc Recorder	2-53
	2.6.7 Monitor	2-53
	2.6.8 Power Supplies	2-53
III	DESCRIPTION OF DEVELOPMENT	
	3.1 Proposed System	3-1
	3.2 Design Considerations	3-4
	3.2.1 GFE Equipment	3-4
	3.2.2 Converter Screen	3-6
	3.2.3 Optics	3-7
	3.2.4 Image Intensifier-SEC Vidicon Package	3-9

TABLE OF CONTENTS

Section		Page
	3.2.5 Scan Converter	3-13
	3.2.6 Alternate Scan Converter	3-13
	3.2.7 Contrast Enhancement	3-17
	3.2.8 Monitor	3-19
	3.2.9 Mechanical Considerations	3-19
	3.2.10 Change to Scope of Work	3-22
	3.2.11 System Equipment	3-23
3.3	Design Development	3-23
	3.3.1 Literature Search	3-23
	3.3.2 SEC Vidicon Camera System	3-24
	3.3.3 Scan Converter	3-27
 IV	 SYSTEM TESTING	
	4.1 MSFC Neutron Test Facility	4-1
	4.2 Source Characteristics	4-4
	4.3 Preacceptance Test at Argonne National Laboratories	4-8
	4.4 Van de Graaff Acceptance Test	4-10
	4.5 Test Conclusions	4-13
 V	 RECOMMENDATIONS	
 VI	 BIBLIOGRAPHY	

1. INTRODUCTION

Contract No. NAS8-30070 was issued by George C. Marshall Space Flight Center to Zenith Radio Corporation on June 28, 1968. The purpose of the contract was the modification of an X-ray television system into a neutron radiographic viewing system for nondestructive testing uses. This was to have been accomplished by (1) performing a comprehensive study of neutron radiographic imaging by television; (2) modifying Government-furnished equipment (television monitor and scan playback subsystem); (3) fabricating or furnishing required items of the system (image converter, image amplifier, lens system, SEC vidicon tube, connecting cable); and (4) performing a complete system integration and checkout.

The final system was to meet the following criteria: (1) the image converting device, used to convert thermal neutron flux into light, was to have a minimum resolution of 0.01 inches, be compatible with the input requirements of the television camera, and be integrated into a single unit with the camera for remote location operation; (2) the television camera was to be enclosed in a lightproof, electrically interlocked housing, with a volume of three cubic feet or less; (3) the camera must be capable of imaging from 1:1 (full-size) to 10:1 (reduction) for viewing large areas; (4) the final system was to have been tested using a neutron flux of $1 \times 10^5 \text{ N/cm}^2/\text{sec}$ (moderated and collimated) and produce images of 0.010" diameter objects.

Due to difficulties in obtaining a calibrated neutron source, completion of the 13-month program was delayed. The final system installed at Marshall Space Flight Center indicated, by tests run to date, that it met or exceeded the requirements listed above.

2. END ITEM DESCRIPTION

This section provides a description of the problem, a brief introduction to neutron radiographic theory, a description of the system developed under this contract, and information on each unit of the system.

2.1 Statement of the Problem

The objective of the program was to develop and fabricate a neutron radiographic television imaging system to provide useful information at low neutron flux levels. Quality Assurance personnel are required to conduct tests on a wide variety of product properties in order to maintain the quality of the manufactured item. Unfortunately, certain characteristics of the product are impossible to inspect after assembly because of opaque cases or enclosures. Some items in which neutron radiography may aid in the solution of these inspection problems include: the bonding of honeycomb materials used in missile and aircraft structures, explosive trains used in ammunition and explosive bolts, and--to a certain degree--water concentration and the position of certain types of insulation and seals in hydraulic valves or electrical connections.

The fundamental problem in all the aforementioned structures is that the contrast caused by the material under investigation is insufficient to provide a usable image when using conventional nondestructive methods such as X-ray radiation. The present approach used by Quality Assurance for this type of material is to run a batch sampling plan in which a number of items

in each manufactured batch are subjected to a destructive test. In the event that the reject or failure rate exceeds a certain predetermined limit, the entire batch may be rejected. This approach, commonly used in industry, is a stop-gap type, since a probability exists that accepted batches still contain faulty or defective items, while rejected batches might contain a large proportion of acceptable items. This situation has forced designers to add additional safety factors into systems which must function without failure.

2.2 Neutron Radiography

A method which has been under investigation for 20 years and offers an approach by which some increase in the capabilities for nondestructive testing of hydrogenous materials and materials containing such elements as boron, lithium, cadmium and heavy elements is neutron radiography. Although investigated prior to World War II, it received a large amount of attention only after large-scale sources of neutron fluxes became available from the nuclear reactor. A classic book on this subject¹ proceeded to bring under one cover most of the known material in this area.

The principle of neutron radiography lies in the fact that the absorption characteristics of X-rays and neutrons are radically different, in some cases almost opposite. The

1 "Neutron Radiography", H. Berger, Elsevier Publishing Co., 1965.

attenuation of neutrons for a given material, in combination with the classification of neutrons into an arbitrary but predictable system of energy levels, provides the key to radiographic study: the capability for discrimination between different materials. This is primarily due to the probability that the larger the cross-section of a given nucleus, the greater the chance that an approaching neutron will be absorbed or scattered. The detection of the pattern caused by absorption or scattering, by photographic and non-photographic methods, is called neutron imaging detection and provides the operator with visible radiographic evidence of the test specimen's structure.

Basically, neutron radiography provides a useful complement to such nondestructive testing methods as X-rays, infrared, ultraviolet and ultrasonics. It can provide discrimination in heavy metals over a large range of thicknesses; high-contrast resolution capabilities; a thermal neutron image in the presence of high gamma radiation intensity; and extreme sensitivity to certain materials which, being neutron-absorbing, yield useful radiographic images. These capabilities make neutron radiography particularly applicable to such fields as reactor, rocket and missile technology; biological studies; and plastics and heavy metals inspection.

Although commercial neutron radiographic services are available to the public, they are generally associated with a nuclear reactor and require that the specimen under study

be brought to the reactor rather than vice versa. Almost all neutron radiographs made in the past and at present are made by a conversion screen technique. Either a special conversion screen is made radioactive due to bombardment by thermal neutrons, or by a direct conversion technique where the thermal neutrons are converted into some other form of radiation, such as light or electrons, and then are used to activate photographic film. Besides the problems of cost, these techniques are time-consuming and usually require a large reactor source if the radiograph is to be made in less than one hour.

The purpose of this program then becomes one of providing a method of direct viewing of a neutron radiographic image which is being generated by a small portable source. The neutron source was to be supplied by the nondestructive test research group at Marshall Space Flight Center, NASA, Huntsville, Alabama. The specific design goals of the program were described in Section 1.

2.2.1 The Neutron. The neutron can be thought of as a fundamental particle in that it contains fundamental properties which are entirely its own. The mass of a neutron is now accepted as being 1.008982 AMU (atomic mass unit). The neutron, outside of the nucleus, is unstable and has a decay cycle in which a beta particle plus a neutrino are emitted, leaving a proton. The half-life of the neutron has been calculated as being 12.8 minutes. Neutrons have been classified by their energy which, in turn, indicates their velocity.

2.2.1.1 Ultra-High-Energy Neutrons. Neutrons with energies in excess of 50 MeV are defined as ultra-high-energy neutrons. Very little work has been done with particles in this area, but sufficient effort in the 1 to 5 BeV region indicates that fission and spallation of nuclei can occur in atomic numbers below bismuth as well as above it. Most nuclei appear transparent to neutrons in the BeV range. Cosmic radiation and linear accelerators are sources of ultra-high-energy neutrons. Above 20 MeV, all neutrons are considered to be relative.

2.2.1.2 High Energy Neutrons. High energy or fast neutrons are considered to operate from approximately 20 MeV down to 10 keV. It should be noted that many of the natural radioactive sources tend to emit neutrons in this particular range by radioactive decay.

2.2.1.3 Epithermal Neutrons. This range of neutron energies is defined as being from 10^4 eV down to 0.3 eV. It contains a distribution of neutron velocity which exceeds any permitted by Maxwell distribution for the temperature of a moderating material.

2.2.1.4 Thermal Neutrons. When neutrons are traveling at an average energy that is equal to the average thermal energy of the atoms of the mediums that they are in, the neutrons are classified as thermal neutrons. The energy and corresponding velocities depend upon the temperatures of the medium. At room temperature, this energy is 0.025 eV and the range for

thermal neutrons is considered to vary from 0.01 to 0.3 eV.

2.2.1.5 Cold Neutrons. Cold neutrons are neutrons whose average energies lie below 0.01 eV. It should be noted that they are not produced by refrigeration. Their energies are well under those of the atoms due to thermal agitation at room temperature.

"Slow" neutrons are usually considered to be those neutrons with energies less than 1 keV and "intermediate" neutrons in the energy range existing between 1,000 eV and 0.5 MeV.

Finally, the "high" energies are listed as running from 0.5 MeV to at least 10 MeV. The "ultra-high" energies are above 50 MeV. It should be noted that neutron radiographic techniques used in this program are limited to neutrons of thermal energies only.

2.2.2 The Neutron Radiograph. The basic philosophy used in obtaining a neutron radiograph of a specific subject is to radiate the subject with a uniform thermal neutron flux. The radiation flux level is attenuated by the subject and the resultant effect is to provide a spatial modulation of the neutron flux. This resultant spatial modulation is the neutron "signature" of the subject. An identical approach, allowing radiation to penetrate the subject, is used in X-ray radiography, where the X-ray quanta are either absorbed, scattered, or converted by the atomic structure of the subject under investigation. The radiographer seeks to collect only those primary quanta which pass through the

subject. These quanta are then converted in some manner such as film, image intensifiers or X-ray-sensitive television tubes so that visual images can be seen. Contrast is required to allow the determination of the shape of the subject throughout the total area viewed. If the subject were made of a homogeneous material, it would have no contrast, and no shape or form could be determined by the radiographer. Thus, it is necessary, if images are to be visible, to have variation in the spatial absorption characteristics of the subject with respect to the radiation being used.

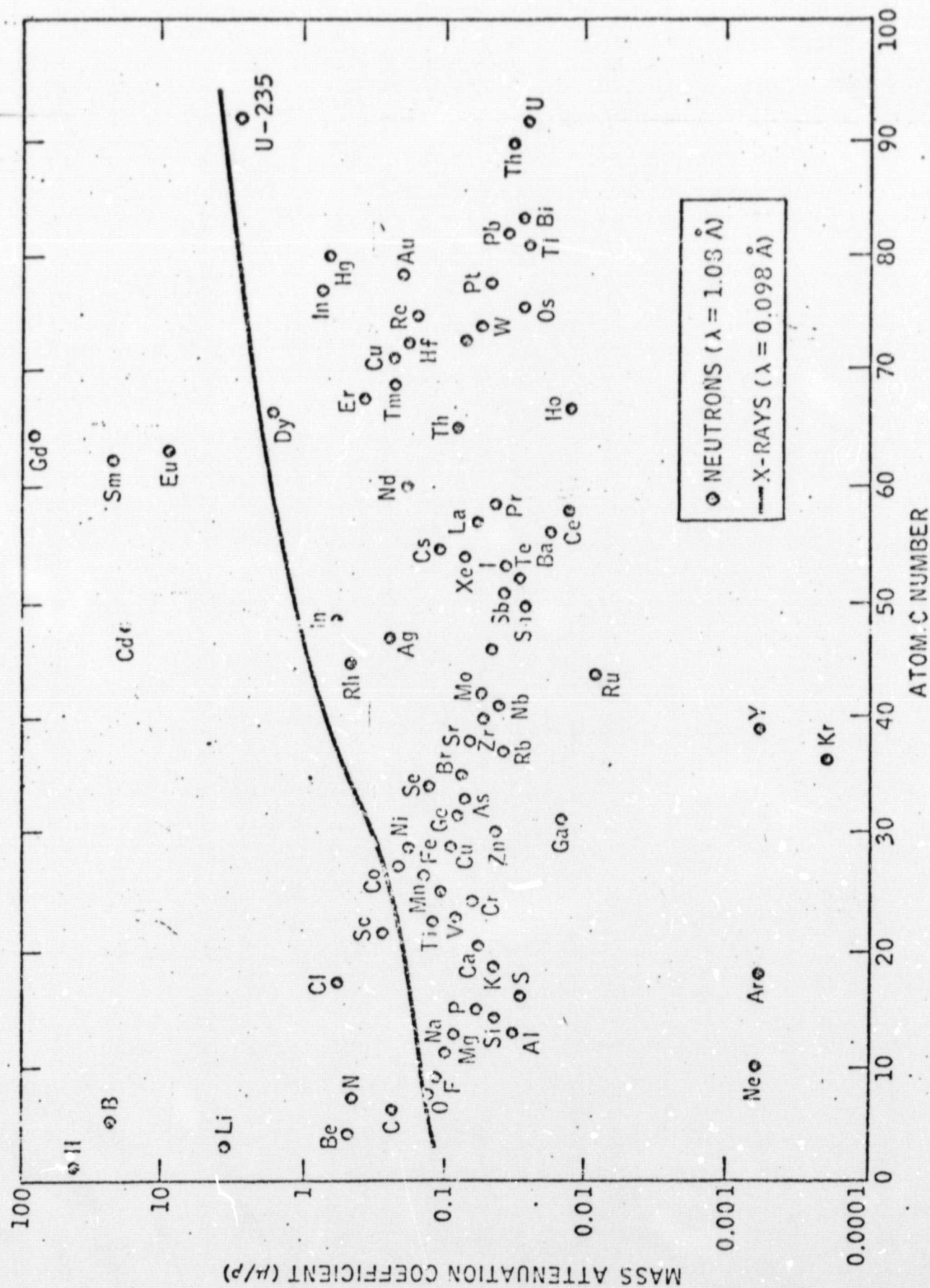
The mass absorption coefficient for X-rays generally increases with the fourth power of the atomic number of material. Thus, one inch of lead tends to stop far more X-ray photons than does one inch of hydrogen under standard conditions. The mechanism for neutron absorption and scatter is entirely different from that of X-rays since it is the nucleus and not the atomic structure which interacts with the neutron. It is not surprising, then, that the mass absorption coefficient of many elements for neutron attenuation are far different than for X-rays. As an example, hydrogen, which is close to being transparent with respect to X-rays, has a mass absorption coefficient of over 40 as compared to lead, whose thermal neutron mass absorption coefficient is only 0.45. Thus, one would expect that with a combination of lead and hydrogen layers the hydrogen effects on neutrons would be much more visible than those caused by lead. Other materials which are

highly sensitive to special thermal neutrons include boron, lithium, cadmium, indium, and gadolinium. Thus, the neutron radiograph can be expected to give additional information over that of X-ray radiographs for items containing these elements when enclosed in many materials such as steel, brass and lead.

Neutron radiography can be considered to be complementary to X-ray radiography and generally should not be considered as a substitute in the area of nondestructive testing. A plot of the mass absorption coefficient of a number of elements versus their atomic number with respect for neutrons is shown in Figure 2-1. Note that a line showing the X-ray mass absorption coefficient is quite different from that showing the neutron.

2.3 System Considerations

As indicated previously, the basic objective was to supply hardware which would provide neutron radiographic images from a wide variety of neutron sources. In many cases these sources would have neutron fluxes less than 10^5 N/cm²/sec. Thus, the problem becomes one of not only converting the image into a form which can be presented to an observer, but one of providing an integration capability so that sufficient information can be collected to provide the resolutions necessary for nondestructive test interpretations. A block diagram of the key system items to be investigated is shown in Figure 2-2.



Mass Attenuation Coefficient vs Atomic Number
Figure 2-1

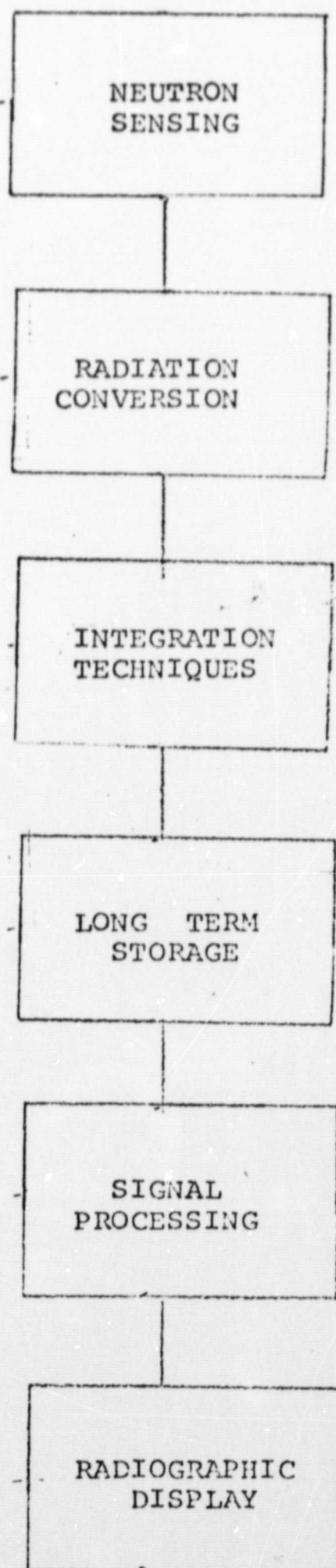


FIGURE 2-2

2.3.1 Neutron Conversion. The first problem area was that of converting the neutron into some other form of energy which is more easily used to display the information to the observer (see Figure 2-3). Several approaches to this conversion problem were to be considered.

The conversion of thermal neutrons to other forms of energy is generally accomplished in the following manner:

1. Capture of the thermal neutron by the nucleus of one of a number of special elements. The energy state is changed and the entire nucleus becomes unstable.
2. The decay of the nucleus by the emission of energetic particles and energy emission. This radioactive decay may be by fission in some reactions.
3. These particles and radiation from the decay process may be used directly to initiate electrochemical reactions (photographic film) or may be converted into some other form of radiation.
4. Other forms of radiation may be generated in the visible or ultraviolet portion of the spectrum.

This light may then be used directly or further converted into electrons. The final form of the output of the converter will depend on many factors, including the signal-to-noise ratio of the system and the nature of the subject size with relation to realizable hardware implementation.

2.3.2 Light Coupling. Two methods are readily available today for the coupling of light between a light producer and a

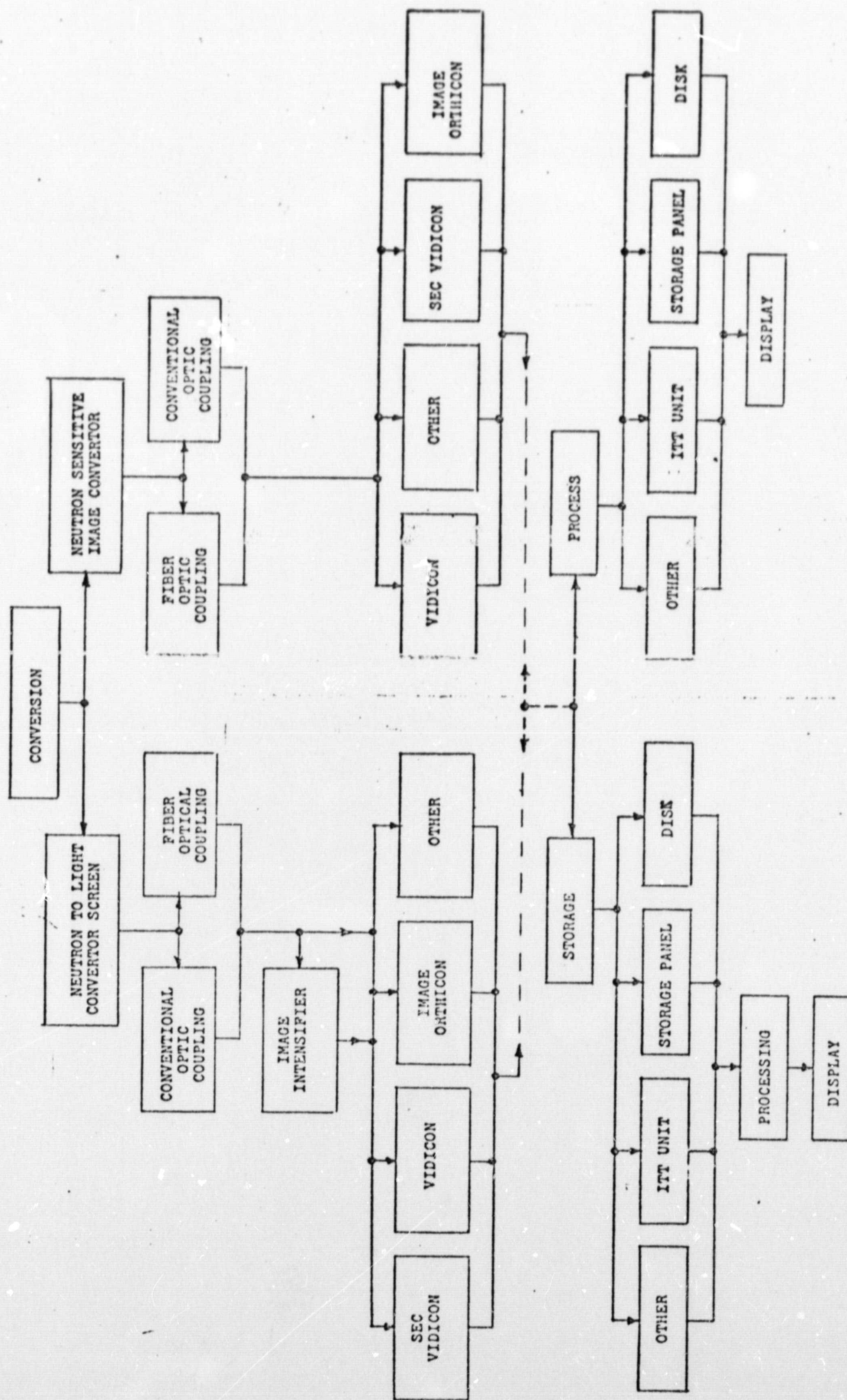


Figure 2-3
Conversion Possibilities

television pickup device: conventional optics in which a lens structure or mirror structure is utilized, and fiber optics in which light quanta is essentially piped from one source to the other. Fiber optics has the highest light-transmitting capabilities, with as much as 50% of the original energy being transferred via the fiber bundle. However, these fiber bundles generally have the same input and output image size. They have a limitation in resolution of approximately 40 line pairs per millimeter, and the overall diameter is usually under a few inches.

Conventional optics suffer from a general light loss which can be predicted by the formula

$$\frac{I_0}{I_{in}} = \frac{1}{4T^2(1+M)^2}$$

where: I_0 = light intensity out of lens

T = lens T-number

M = ratio of image to object size

Note that for a magnification of 1 and a T number of 1 (which is a relatively high-performance lens), a factor of only 1/16 or roughly 6% of the light can be transmitted through a single lens. This high light loss can be reduced by utilizing a dual lens system using the collimating lens and imaging lens. As much as 20% of the object brightness could be expected in the image. This lens approach, moreover, has the advantage of allowing demagnification and variation in amount of

magnification. Thus, larger subjects can be investigated with a fixed size format photocathode in a pickup tube. In addition, the lens structure is also sufficiently flexible so that various sized viewing areas can be easily selected. This feature may prove useful.

In the event light is taken directly from a conversion screen and sent through an optical system, some form of light amplification would probably be necessary. The light image intensifier tube can provide amplification factors up into the thousands. In addition, solid-state light amplifiers are being developed which may become generally available in the near future. The image intensifier can generally provide adequate light gain and would probably have sufficient resolution for the system. Potential noise problems are considered in another section of this report.

2.3.3 Image Converters. An alternate approach to converting the neutron image to a light image and then coupling via optics to a TV pickup tube is through an image intensifying technique. This approach uses a neutron image intensifier tube which has the following basic sections: photocathode, accelerators, and output screen.

The photocathode converts the thermal neutron to electrons which are emitted with only a few electron-volts of energy. Initial steps in this process are identical to those described in paragraph 2.3.1, with the resultant radiation being in the form of visible light energy. A photoemissive coating on top

of the conversion material then captures the light photons and emits electrons.

At this time, the most effective material for thermal neutron conversion in image intensifier tubes has been lithium 6 (L^6F). Although its linear absorption cross-section is rather modest (2 at a thermal neutron wavelength of 1.08 angstroms) the alpha and byproduct (tritium) of the reaction is very efficient in the production of light photons in phosphors.

Other possible candidates for thermal neutron conversion include boron with a linear absorption coefficient of 60. However, the particles resulting from this reaction are not as effective in producing photons as those produced in the lithium reaction. Other materials such as gold, platinum, cadmium and uranium either do not produce efficient by-products for photon production, or have a decay cycle with long time constants. The long time constant would prevent dynamic imaging.

One additional tradeoff for consideration is the thickness of the conversion layers. As the L^6F neutron conversion layer thickens, the conversion efficiency increases. However, the byproducts of the conversion process are more readily trapped in the thicker layer as are the photons, both of which are very energetic and tend to be fairly effective in producing photons in the cadmium sulphide. A particular problem arises in this mixture in that it becomes more

efficient as it becomes thicker. However, the loss of photons in the basic material finally causes diminishing returns in the overall number of photons produced per neutrons. This drop-off is generally found in thicknesses which vary between 0.005 and 0.020 inches. The thinner screen can lead to better resolutions in the system. This process in either approach seems to be the most promising. It should be noted that the block diagram (Figure 2-2) splits at this conversion point with the output being either light or electrons. In the event that a neutron-sensitive image converter is utilized, the ultimate output after amplification of the basic photo-emitted electrons is light. At this point, the problem then arises as to how to couple this to some sort of storage pickup device. This will now be considered.

The conversion of the light image into an electron form is an important problem in this program. Fortunately, the vast amount of research in the television industry has provided a wealth of performance criteria for the optimizing section of the system. Important items to take into consideration in this conversion process are:

1. Efficiency of conversion
2. Repeatability, ease of maintenance, and ease of operation of the pickup device
3. Faithfulness of reproduction, including such items as grey shades, signal-to-noise ratio, fixed pattern noise, and resolution

4. Other advantages, such as variable scan rate, and extended integration capabilities.
5. Compatibility with other items in the system.

Although a number of television camera tubes have been developed in the last 40 years, only three basic types now appear readily available and directly applicable to this system. Such items as the image dissector tubes and various types of flying spot scanner photomultiplier systems have a basic flaw in that they are investigating only a single small section of the image at any one time and have virtually no storage capabilities. This is such a fundamental necessity for this system that they are immediately disregarded.

The three basic types of standard commercially available television camera tubes which bear consideration are the vidicon, SEC vidicon and image orthicon. (The silicon target vidicon was not available during the study phase of this program and therefore was not included.) The smallest physically, and the least sensitive lightwise, is the standard vidicon tube. Figure 2-4 shows the light-operational performance characteristics of the various tubes mentioned. It should be noted that the standard vidicons generally are not useful at light levels under 0.1 foot-candles on their photocathodes. Vidicon tubes can be obtained with resolution capabilities of 1,000 television lines across the horizontal section of the tube.

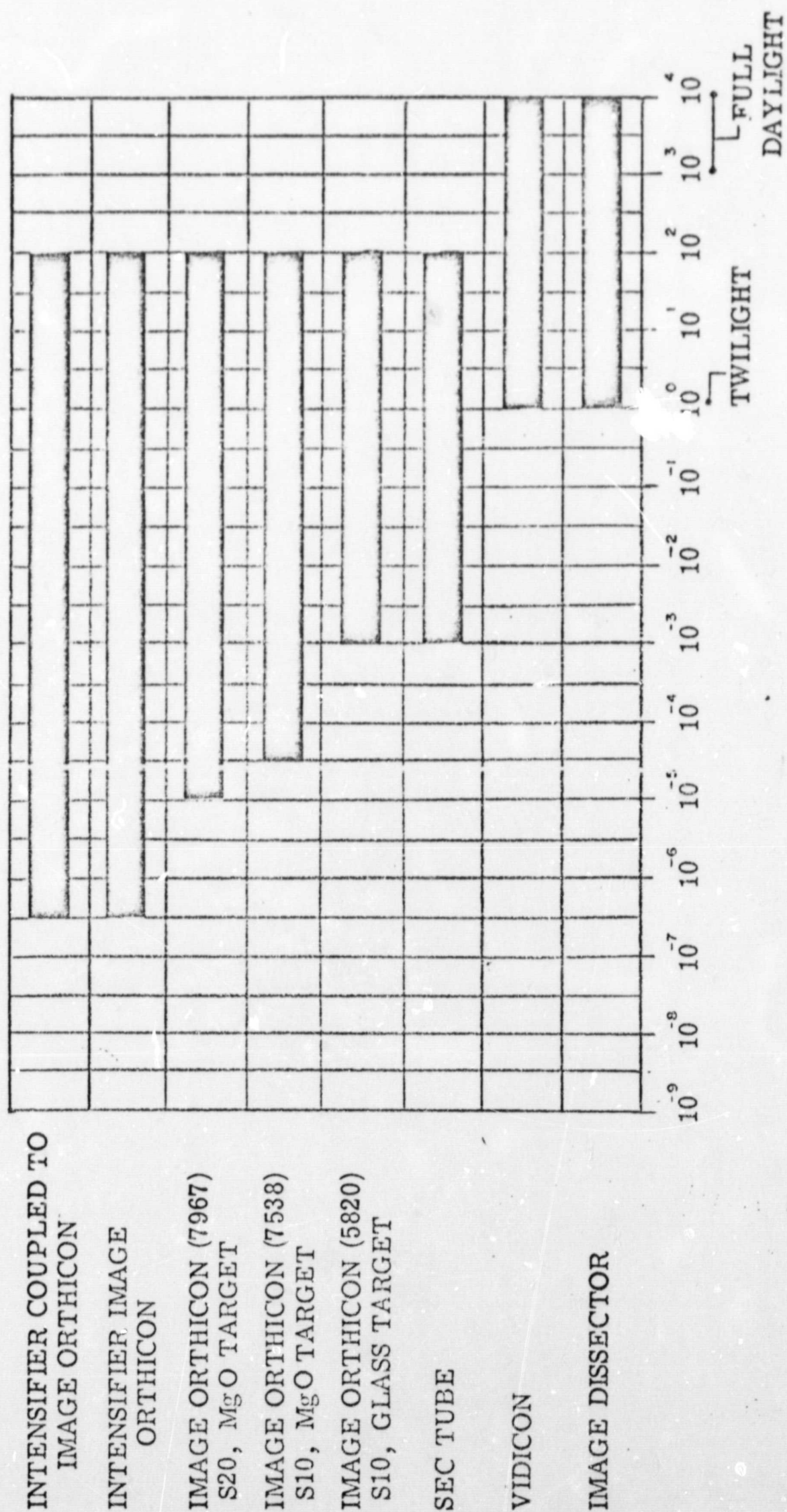


Figure 2-4. Light-Operational Tube Performance

In addition, special-purpose vidicon tubes can be obtained that have extended storage periods; however, the vidicon tube is generally manufactured for a particular storage time and not a wide range of storage times. The vidicon tube is quite rugged, tends to be rather simple for an operator to operate and maintain once set up, and tends to be the lowest cost camera of any of the previous mentioned. The basic principle of photoconduction utilized in the vidicon has allowed special purpose X-ray-sensitive vidicons to be produced, and vidicon tubes which operate into the near-infrared region. At high light levels the vidicon tube gives a rather high signal-to-noise ratio, which is claimed to be in excess of 300 to 1. One has to be very careful about the definition of signal-to-noise ratios and their significance in the performance of this system. The signal-to-noise ratio given for one type of tube from one manufacturer may not be directly comparable to signal-to-noise ratios of other type of tubes produced by other manufacturers, or even the same manufacturer.

The SEC vidicon is larger than the standard vidicon and uses an entirely different principle for the conversion and storage of light information. The readout principle, however, is similar to that of a vidicon and probably is the reason that it bears the term vidicon. Note that the performance of the SEC vidicon with respect to light level is extended into the region of 10^{-5} foot-lamberts. The present SEC vidicons do not appear to have signal-to-noise ratios as great as vidicons

at their best; however, they have a useful characteristic in that the readout can be selected over a wide range of storage intervals. The SEC vidicon thus has the capability of allowing integration of information on its storage element with a readout rate selectable by an observer. The basic conversion is by a photoelectron emitter process in the imaging or front section of the SEC vidicon. The photo-electrons are then accelerated through an electrostatic potential which varies between 3 and 7 kV, and strike a specially prepared target. The energetic photoelectrons then tend to provide a charge pattern on the target which is periodically read out by a scanning beam coming from the rear, or scanning section of the tubes. Although these tubes can use a number of photoemitting materials in the imaging section, their performance is generally limited to the range between the very near-infrared and the ultraviolet.

The most sensitive single tubes in today's market are generally regarded to be the image orthicons. (The image isocon is similar to the image orthicon except in the readout section. In theory it should provide superior performance to the image orthicon, but it suffers from storage problems.) These tubes have an imaging section similar to that of the SEC vidicon, but use a special target which utilizes secondary electrons for electron gain. The readout process of the image orthicon, however, is different in that a low velocity beam is used to recharge the target, and then is returned to an electron

multiplier stage where an amplification of approximately 300 to 500 occurs. The image orthicon is generally considered to be the most fragile of the three types mentioned, and generally is the largest, occupying twice or more the volume of the other devices. In addition, a larger number of grids are associated with the image orthicon, and the set-up of the image orthicon tube together with its control maintenance is more complicated than the other tubes mentioned. The sensitivity under the best of conditions is better in the image orthicon by at least one order of magnitude of light level; however, the signal-to-noise ratios at lower light levels leave much to be desired, and special low light level image orthicons do not present the high signal-to-noise ratios encountered in commercial television. The resolution in the larger image orthicon tubes can reach 1,000 lines. The image orthicon can also be purchased with special targets which are very useful for long term integration. However, the integration time is pretty specific, and though one tube can be designed to provide storage for long periods of time, the period of time is pretty well fixed and cannot be varied.

In summation, the medium sensitivity of the SEC vidicon tube, coupled with the variability of the integrating characteristics of this device, make it uniquely suitable for this particular system. Although the signal-to-noise ratio is not as high as vidicons under their best operating conditions, and the resolution is not as high as either the vidicon or

image orthicon when these tubes are operating under optimum conditions, the SEC vidicon appears uniquely suitable to this particular application

2.3.4 Pickup Device. Independent of the method of conversion and initial optical coupling is the problems of converting the optical or radiation information into an electronic form.

Although it is feasible to go directly from light to electronic form by using some sort of storage target system, the requirement to produce hardware on this system generally indicates the use of existing conversion devices. Fortunately, a number of these devices are readily available on the present market.

2.3.4.1 Vidicons. Considering the basic types of devices, the least sensitive of any is the basic vidicon camera tube. This tube depends upon a photoconduction process for its operation. The tube contains a target made of photoconducting semiconductor material, focusing electrodes and an electron gun which provides a relatively low energy scanning beam. The beam scanning the target tends to deposit an electron layer on the gun side of the target. On the opposite side of the target is a transparent conducting coating which is connected to the target voltage via a resistor. Under conditions of no light, a so-called dark current appears, which is a leakage current between the electron layer deposited on the gun side of the target and the target voltages passing through the load resistor on the front side of the target. When light strikes the target, charge carriers are induced inside the semiconductor region

and tend to drift under the influence of the potential difference on the target to the rear of the target, tending to neutralize local areas of charge. Since the beam from the electron gun is scanning in the form of a rectangular raster, the charge modification is not affected until it is rapidly replenished by the electron beam as it scans over the affected areas. The displacement current generated by this redistribution of the charge upon scanning, is immediately translated to a current variation across the target load resistor. This voltage provides the electrical signal which is proportional to the intensity of the light accumulated between two scans of the appropriate position on the target. As a result, the current variation across the target load resistor is directly proportional to the intensity of the patterns imaged on the target of the vidicon.

Using the standard EIA scanning rates, the sensitivities of readily available vidicons vary from a maximum resolution of between 400 to 1,000 television lines, at faceplate illuminations varying from as high as 100 down to 1/10 foot-candle. Advancements in vidicon technology have provided units called plumbicons with sensitivities that can provide maximum resolutions and ten shades of grey at levels on the order of 10^2 foot-candles.

In addition, other special purpose vidicons can be so designed as to allow slow scanning techniques which allow integration and appropriately increase apparent gain of the

system. However, these tubes are not really versatile with respect to wide variations in the scanning rates, and as such, are generally designed for their particular applications. The vidicon provides a splendid electrical signal in a small package and is generally the least expensive of the various approaches considered.

2.3.4.2 Image Orthicon. Another readily available tube, being used quite often in studios, is the image orthicon. The image orthicon combines several basic principles of operation to form a final transducer, and can be thought of as essentially two separate and unique sections: the imaging section and the scanning section. The imaging section converts light photons to photo-electrons and proceeds to energize these electrons and focus them on a target. Thus the pattern of the original image is written upon the target located between the imaging and the scanning section of the tube, with electron densities proportional to the amount of localized illumination on the photocathode of the imaging section.

The target, which is common to both the imaging and scanning sections, may operate under a number of different principles. The target itself is always very thin, ranging from 1/10,000 of an inch down to 500 to 600 angstroms in thickness. The characteristics of these targets are such that the leakage passed through the target material from the front to the back is of a reasonable amount; however, the lateral leakage along the target surface is held to a minimum. Like the vidicon,

the electron charge on the face of the target on the imaging side is allowed to leak through the target to the scanning side of the target. The scanning section contains a relatively low velocity beam which travels from an electron gun through various focusing sections of the tube and then strikes the target with a relatively low velocity of under 1 or 2 eV. This deposits an electron charge which is uniformly distributed over the target by the beam scan. The beam has sufficiently high density so that a normal dark current returns to the gun from which it was generated. The anode of the gun has the first surface of an electron multiplier. Generally, the return beam is amplified by a factor of 500, giving almost noiseless electronic gain as delivered to an output electrode.

The overall process in the image orthicon then becomes as follows: The scanning beam proceeds to place a charge on the back portion of the target. After this charge has been deposited, further scans result in a full return of the scanning beam to the first anode located at the electron gun of an electron multiplier. The output of the tube, at this time, is a maximum current. This is called the dark, or black, current. The scene, having a variation in light intensity, is focused on the photocathode in the imaging section of the tube. Light photons are used to generate photoelectrons which are then accelerated through the imaging focusing section of the tube and strike the front or imaging side of the target area.

Upon being struck by electrons, the target, generally through secondary emission, accumulates a positive charge. The secondary electrons are then collected by a collector ring around the target. Thus a potential exists across the target created by the incoming light-created electrons in the imaging section, as compared to the uniform negative charge distributed by the electron beam in the scanning section. The pattern on the scanning side is then modified by leakage of the charge on the scanning side through to the positive portions on the imaging side of the target. When the scanning beam strikes the section of the target whose charge density has been modified by the imaging process, portions of this beam are removed and used to neutralize the different charge levels. The remaining portion of the beam is returned to the gun section and the first anode of the electron multiplier is then amplified. Note that as the optical image becomes whiter (higher light level), the return beam to the electron multiplier becomes less and the output of the related scanning section becomes less. The general point of operation of this tube is adjusted such that the return beam is zero at the highest white levels in the system.

The image orthicon can be utilized at lower light levels than the vidicon and generally can provide pictures with light levels down to 10^{-6} foot candles or better. Image orthicons have been used in slow scan and integration modes, and have been used in astronomy for years with very special cooling techniques in

the region of the photocathode. The image orthicon is generally thought to be at least three magnitudes more sensitive than the vidicon, and in some cases can be used at levels as low as 10^{-8} foot candles. However, the signal-to-noise ratio from image orthicons is generally higher than that found in vidicons, and in addition, the image orthicon is almost always larger than the vidicon. In some cases, the sizes of image orthicons reach over 4" in diameter and tend to be up to 14" to 20" in length. The image orthicon tends to have a more complicated power supply and requires more correction in its operation. It is a more sensitive device both mechanically and electrically, and is more easily damaged by improper operation.

2.3.4.3 SEC Vidicon. The SEC vidicon has a performance characteristic which falls midway between the best vidicon and the best image orthicon. The SEC vidicon, like the image orthicon, contains both an imaging and a scanning section. The readout mode, however, is more on the nature of the vidicon rather than the image orthicon in that there is no low-velocity return beam to contend with. The imaging section of the SEC vidicon is identical to that of the image orthicon with the possible exception that the potentials encountered are far greater. Normally, the image orthicon has a potential difference between photocathode and target on the order of 600V to 1,000V. The imaging potential between photocathode and target of the SEC vidicon varies from 3 kV to as high as 7 or 8 kV. Thus, a substantial gain can be accomplished in

the target structure itself by the bombardment of the high-velocity photoelectrons. The term SEC designates Secondary Electron Conduction, and is a description of the target material. The target, which is a very light form of potassium chloride and is on the order of 500 angstroms thick, when bombarded by high-energy electrons will release a number of secondary electrons into the interstitial space between the lattice centers of potassium chloride.

It should be noted that the potassium chloride layer used in this target has only 5% of the bulk density, and therefore a great portion of the target is actually vacuum space. An electrical field buildup at the back of the target by a high-velocity scanning beam causes these induced secondary electrons to drift towards the scanned surface of the target. The conduction of the secondary electrons takes place in the interstitial space vacuum and not in the charge induction band of the potassium chloride. This process removes the possibility of long persistence because of the release of trapped charge carriers at the storage centers. These electrons drift towards the charge, modifying the charge distribution on the scanning side of the target and creating positive and negative patterns, which in spatial distribution and intensity correspond to the optical image focused on the faceplate of the tube.

The extremely high resistivity of the target provides for very long periods of storage time on the discharge pattern. The scanning beam periodically returns the target potential

to that of the cathode of the gun, resulting in a displacement current similar to a normal vidicon occurring at the target. This current develops a voltage across the load resistor and produces amplification of the video signal from the equipment. Thus a SEC vidicon provides a readout similar to that of a vidicon with the additional gain embodied in a special target amplification phenomenon. Present 25mm faceplate tubes are capable of providing up to 500 lines resolution on static scenes at light levels of 10^3 foot-candles and are useful at levels down to 5×10^{-5} foot-candles on the photocathode.

One of the most striking advantages of the SEC vidicon is its capability of retaining stored charges over long periods of time. This tube seems to have the unique feature of being able to handle wide variations of scanning rates from at least the present EIA scanning standards to storage times in excess of five minutes. The noise level of the SEC vidicon is generally somewhat better than the image orthicon, but poorer than the vidicon when utilized at high light outputs.

Mechanically, the SEC tube falls midway between the size of the vidicon and the image orthicon, and can be made in a relatively light, flexible package.

2.3.4.4 Other Tube Types. Other tube types are available, including developmental work such as the image isocon which operates on much the same principles as the image orthicon, with the single exception that the return beam becomes higher for peak whites and lowest blacks. This phenomena means that

the signal-to-noise ratio is far better at lower light levels than in the image orthicon. The dynamic range of operation is superior. However, the image isocon requires rather elaborate focusing deflection sections and special auxiliary power supplies. As a result, it is even more complicated than the ordinary image orthicon and requires special additional features. In addition, the size of the tube is approximately the same as in image orthicon.

Other tubes include the incorporation of microchannel plates, which are electron multipliers located in the imaging section of the tube in front of a variety of storage target materials. These devices appear to offer great potential for very high gains in the future; however, few, if any, are presently available beyond the development phase. The target materials also offer some problem in variable storage rates.

2.3.5 Storage. Since rather low neutron fluxes are expected in this system, some means of storing video data appears necessary. This is discussed in much greater detail later in this report. The storage medium can occur in a number of forms.

2.4 System Description

The Zenith Neutron Radiographic Viewing System developed for Marshall Space Flight Center under Contract NAS8-30070 displays the neutron image of a test specimen on a television monitor. Although the image is displayed at television scan rates of 30 frames per second to the observer, a controllable variable integration time at the sensor allows the use of

very low flux neutron sources.

The system consists of two sections: a camera head and a control/processor. The camera head, located in the test cell, is comprised of a neutron-sensitive image intensifier system and power supply, and a SEC vidicon camera head. Both systems, with their optics, are housed on a test mount. The control/processing section is mounted in a rack capable of being located at least 75 feet from the test cell. This rack contains a power supply, sync generator and test signal generator chassis, TV monitor, video processor, and video disc recording system. External to this rack is a remote control box used to optimize the performance of the neutron image intensifier tube. Figure 2-5 is a block diagram of the final neutron radiographic display system.

Neither the thermal neutron source nor the specimen is supplied with this system. The remaining equipment is located either in the camera head section or in the control rack section. The neutron image intensifier tube converts the neutron flux into light scintillations with considerable light gain over a conversion screen. The light coming from the output, screen of the image intensifier tube passes through optics to the SEC vidicon camera tube, which stores the light intensity of each scintillation over an operator-controlled period varying from 1/30 of a second up to several hours. The video output of the SEC vidicon is, at the operator's discretion, sent over a 75-foot isolation cable to the SEC vidicon camera control

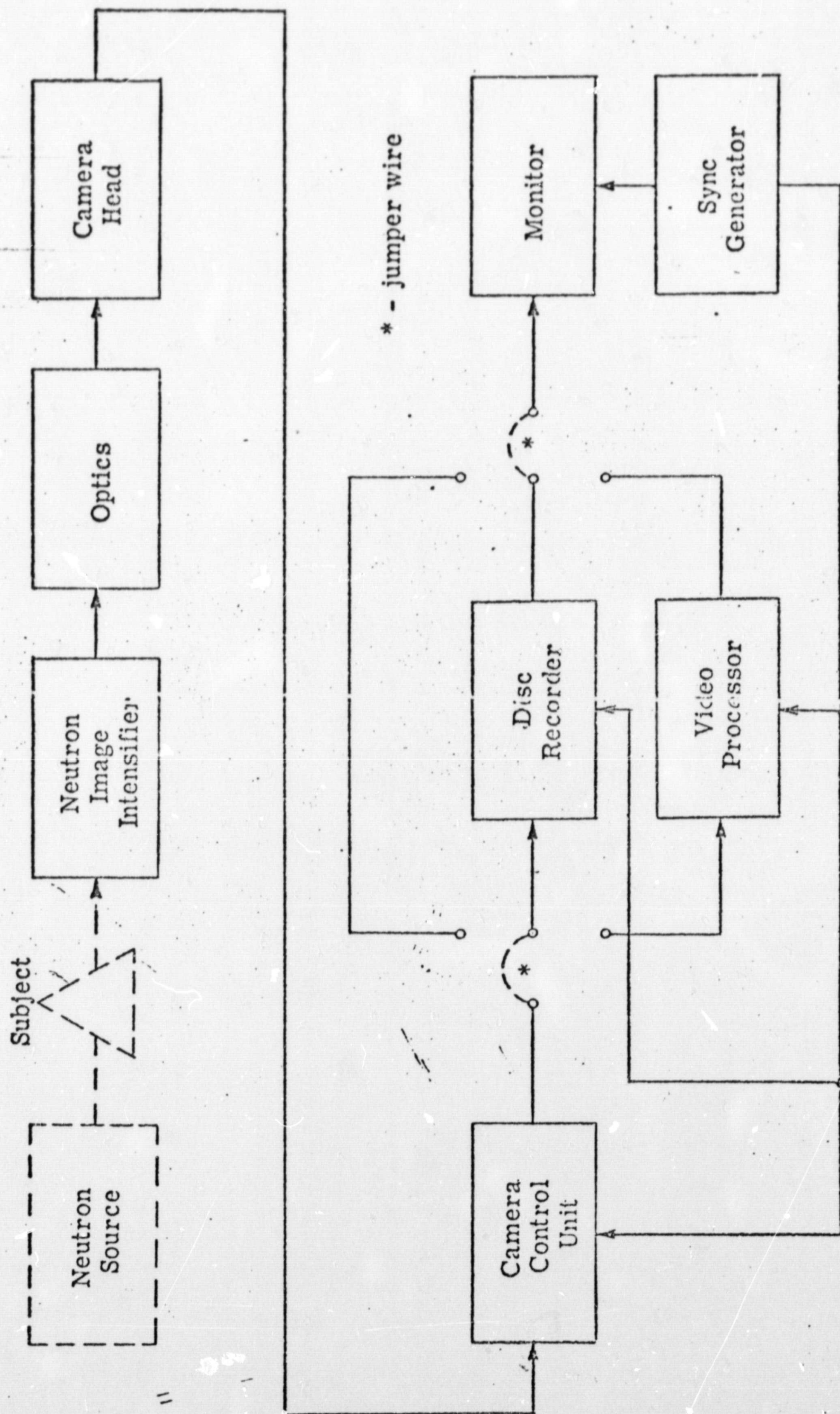


Figure 2-5 Neutron Radiographic Viewing System, Block Diagram

unit. A second cable, connected to a bias control box from the neutron image intensifier tube, allows the operator to remotely peak the performance of the neutron image intensifier tube.

A high voltage power supply for the neutron image intensifier tube is located in the camera head section of the system.

The video signal emanating from the SEC vidicon camera head is amplified, processed and mixed with a sync signal from the sync and control circuits in the camera control unit. The outputs, located in the remote control rack of the camera control unit, are in the form of a composite video signal and a readout control signal. The sync and control circuits provide those signals required to insure proper operation and synchronization of the total system. The sync is normally obtained from stable, crystal-controlled oscillator circuits. Under some forms of alternate usage, a line sync can also be obtained from this equipment.

The purpose of the video disc recorder is to provide a nondestructive readout storage for the neutron image stored on the SEC vidicon. Since the total readout signal from the SEC vidicon is only one television frame for a period of approximately 1/30 second, a continual replay of this single frame is essential to allow visual observation of the neutron image. The output of the video disc recorder is a composite video signal which is sent to the video processor. The video processor allows the operator to expand the grey scale range over a selectable portion of the raster. The processing of

the video in this manner may allow increased ease in the investigation of the neutron radiograph. The output is sent to a standard 525-line 17" TV monitor.

2.4.1 Neutron Image Intensifier. The neutron image intensifier system contains a 12.5-centimeter input image intensifier tube with special dome and photocathode. The electron optic demagnification is approximately 8, with an output image diameter of approximately 1.5 centimeters. The resolution is at least 40 line pairs per inch, and the output screen has the characteristics of P20 phosphor. This tube is placed in a protective housing which contains a high voltage power supply. A remote control box is provided to allow the operator to maximize resolution of this component. This process of maximization is generally not required more than once per installation. Since the tube is irradiated by neutron and gamma flux, a dangerous environment for human beings, it is necessary to remote this function. A 50-millimeter f/1.4 collimating lens is provided as the output optical coupling for the neutron image intensifier package.

2.4.2 Secondary Electron Conduction (SEC) Vidicon Camera. The SEC vidicon camera is a low light level system especially designed to store scenes at very low light levels, and uniquely suited to operating at different storage rates. This modified Westinghouse STV/614 camera system operates at standard 525-line, 2:1 interlace, industrial sync specifications, and is a modified commercial item.

2.4.3 Control Circuits. The control chassis located on the operator's rack is the major source for control functions in the system. Besides providing a patch panel for the operator to manipulate the signal path, switches allow the operator to exercise control over the system. This unit allows the operator to select the sync reference mode, control the operation of the disc recorder, and generate special functions required for set-up of the equipment. A total of eight printed wiring boards plus wiring are supplied in this chassis.

2.4.4 Disc Recorder. A 3600 rpm disc recorder was built to Zenith performance specifications by the Data Disc Corporation. This disc recorder has two read/write channels, and may be used to store two interlaced video fields or one full frame of 30 frame-per-second video information. Alternate field recording is made possible by a field toggle signal which controls the write and read gates on alternate disc revolutions. The operator has the capability of operating this recorder in a read mode, write mode, or automatic periodic write mode. The selection of these modes is accomplished via a switch on the control unit. The upper frequency of this special disc recorder is 6 dB down at 6 MHz.

2.4.5 Video Processor. The video processor accepts video from either the disc recorder or directly from the SEC vidicon camera, depending upon options selected by the operator, and processes these signals under the control of the operator. The processes, selectable by the operator, increase the gamma

in a chosen sector of the raster. The remaining portions of the raster are unaffected by the video processor.

In the section, or window area, selected by the operator, the video information is amplified by a factor of up to 10 times and then clipped so that only a limited voltage range of signal is being viewed. In principle, therefore, the normal 9 or 10 shades of video which can be viewed on an ordinary monitor can be expanded to over 100 shades. With a low-noise video signal, this enables the operator to discriminate between very small changes in contrast in the neutron radiographic image.

2.5 System Specifications

The system is capable of viewing a circular area of either 25 millimeters in diameter or 125 millimeters in diameter. With 100% contrast and a collimated thermal neutron flux of 10^5 N/cm²/sec, images of 0.010" in diameter are visible with the 25 mm viewing area. At lower flux levels, the system is capable of operation using the long-term integration mode. With a 125 mm diameter viewing area, the system resolves at least 40 line pairs per inch at high flux and contrast ratios.

Table 2-1 lists the size, weight, power requirements, and environmental capabilities of the overall system.

Table 2-1. System Characteristics

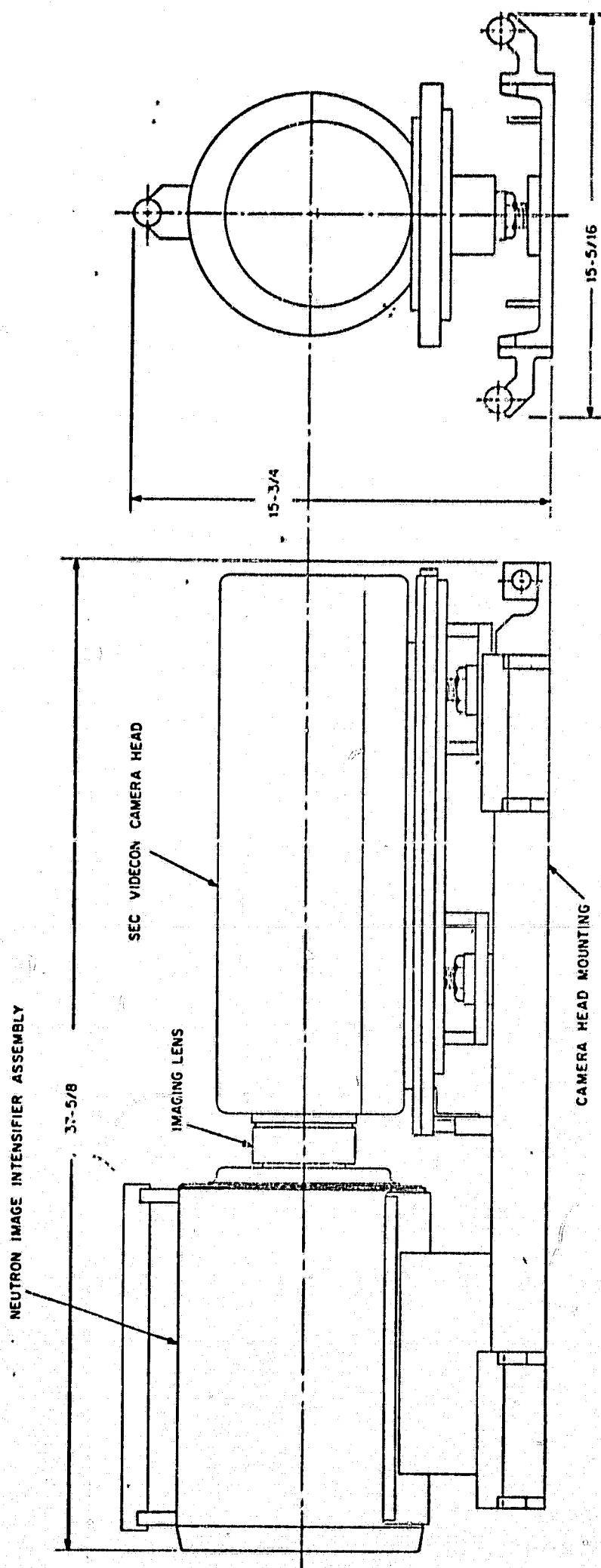
Weight of rack (fully loaded).....	470 lb
Weight of camera head	70 lb
Weight of external cables	32 lb
Overall dimensions	(See Figures 2-6 and 2-7)
Rack power requirements	120 +10% Vrms 750W 60 Hz
Head power requirements	120 +10% Vrms 1.0A max. 60 Hz
Temperature	
Operating	50°F to 105°F (less than 20°F change per hour)
Non-operating	+20°F to +130°F
Humidity (operating).....	20% to 80% relative humidity without condensation
Vibration.....	0.15g max from 1.0 to 60 Hz
Shock	5g max in any axis

2.5.1 GFE and Purchased Equipment Specifications.

2.5.1.1 SEC Vidicon. Refer to the Westinghouse Model STV/614 SEC Television Camera manual for specifications on this unit.

2.5.1.2 Video Disc Recorder. Refer to the manual for the video disc recorder system built for Zenith Radio Corporation for specifications of the video disc recorder and subsystems.

2.5.1.3 Monitor. Refer to the Conrac Type CQC Television Monitor



NOTES:

1. WEIGHT OF:
CAMERA HEAD 70 LB;
CABLES 32 LB
2. CABLE LENGTH:
CAMERA 100FT;
IMAGE INTENSIFIER 100FT
3. POWER REQUIREMENTS:
120V AT CAMERA HEAD
1.0 AMP

Figure 2-6. Camera Head Installation Drawing

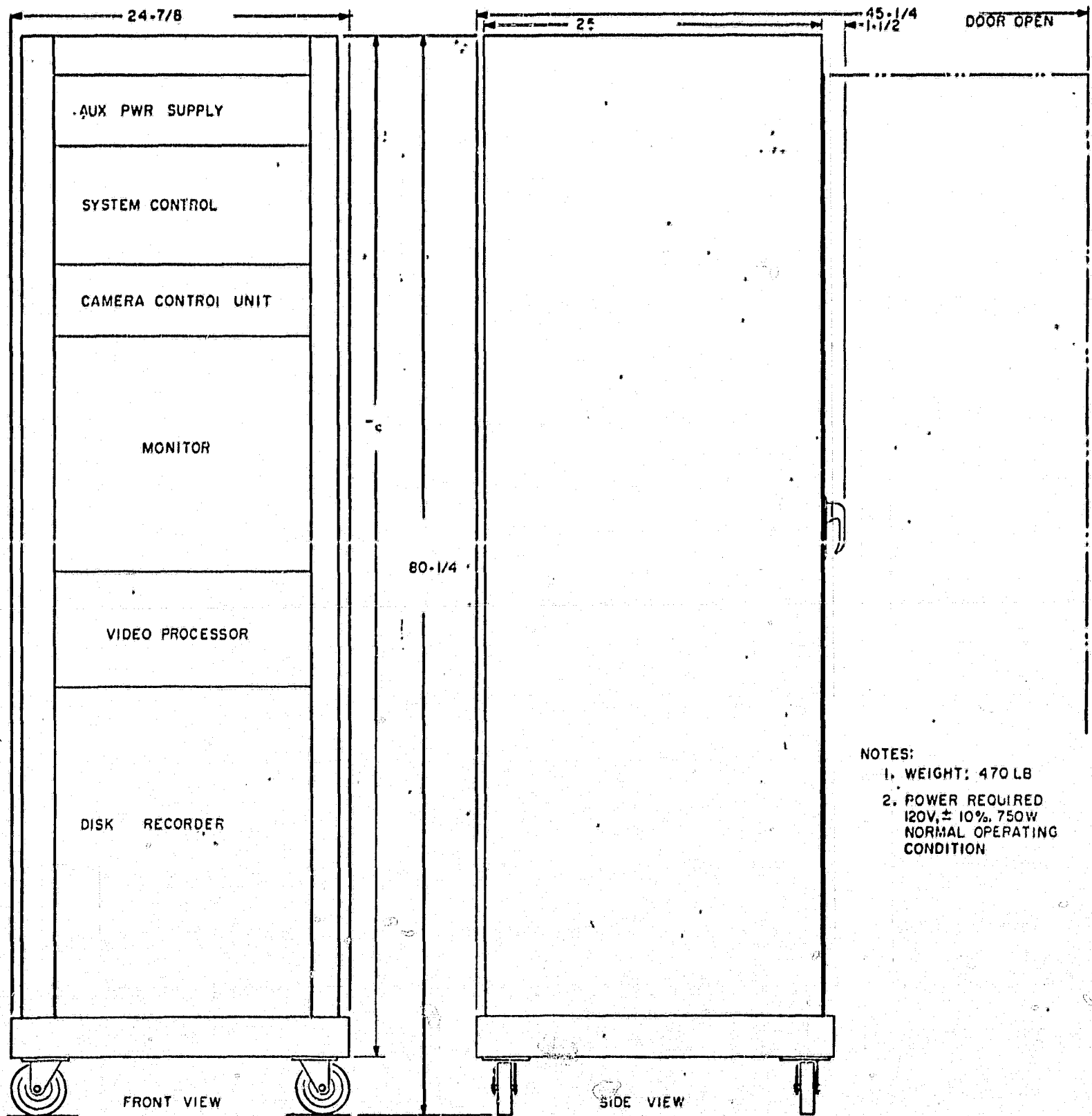


Figure 2-7. Rack Installation Drawing

manual for specifications. Notice that the only modification to the monitor has been a reduction of the line rate to 525 lines per frame.

2.6 System Operation

2.6.1 General. The Neutron Radiographic Viewing System displays the neutron image of a test specimen on a television monitor. In order to accomplish this presentation, the system first converts the neutron flux to visible light flux, and then stores the light image on a television pickup tube. After an integration time sufficiently long to allow the desired resolution, the stored image is read from the television pickup tube in approximately 1/30 of a second and transferred to 1 or 2 tracks of a video disc recorder.

This information is then read back from the video disc recorder at a rate of 30 times per second, and is sent either directly to a television monitor for display or first to a video processor which operates on the data to enhance its intelligibility, and then to the display. The sensing equipment is a self-contained system in that only 115V, 60 Hz power is required to operate this system, together with a user-supplied thermal neutron source. The equipment is normally allowed to warm up for approximately 15 minutes.

2.6.2 Neutron Image Intensifier. The neutron image intensifier is a vacuum diode composed of a neutron-sensitive photocathode, electron optical focusing assembly, and P20 phosphor screen. A potential of 20,000V to 25,000V is applied between the

photocathode and the phosphor screen. In the particular image intensifier tube used for this system, the photocathode is at ground potential while the screen located behind the fiber optic output plate is at a potential of approximately 21,000V.

An incoming neutron enters through the protective aluminum dome to the photocathode. This photocathode material is composed of enriched lithium (^6Li), zinc sulfide and a tri-alkali photoemitting material. Thermal neutrons passing through the dome strike the photocathode material and some are absorbed by the ^6Li nuclei, which results in a prompt disintegration of the nucleus into an alpha particle. These large particles, containing considerable energy, are then scattered and strike the ZnS atoms. Each contact causes a transfer of energy. This places the phosphor in an activated state and results in the emission of photons. The photons, which are in the visible spectral range, are then converted to photoelectrons, which are emitted into the electrical field across the tube.

At this point, with starting energies of a few tenths of an electron-volt, the electrons are then accelerated through a primary field of approximately 21,000V. During this process two grids, G1 and G2, whose voltages are externally controlled, are used to shape the path of the electron flight and cause an image reversal and demagnification of approximately 8:1 at the phosphor plate. The electron striking the P20 phosphor plate again generates light, with light gains of over 20,000

as compared to conventional scintillation screens. The light is then sent through a fiber optic faceplate and is picked up by a collimating lens which is used to couple the light output of the image intensifier to the next portion of the system. The power supplies, tube mounting, and optical alignments are factory-serviced items.

2.6.3 Control System. The control system is composed of eight separate boards fitting into a central connector rack and a front panel. These circuits generate timing and control signals in the system.

2.6.3.1 Oscillator (8661-A8). The crystal-controlled oscillator contains two common-emitter stages with feedback from a collector of the second stage to the base of the first stage. The feedback is through a crystal which is the only frequency-controlling element in the oscillator. This oscillator provides the 31.5 kHz clock required by all portions of the television system.

2.6.3.2 Afc Board (8661-A7) The afc board provides a power-line-synchronized 31.5 kHz clock pulse used to drive the entire system when the crystal mode is unacceptable. This conduction occurs only when there is a significant hum in the system which can be seen as horizontal bars rolling through the picture when the crystal mode is being used. Test have shown that the disc recorder system does not perform well when the additional afc loop is utilized; therefore, the disc recorder cannot be used in this mode of operation. The basic principle of operation

of this oscillator is that the reference 60 Hz line signal is applied to a keyed diode gate. The keying signal is the internal vertical drive pulse which is only a few hundred microseconds long. Thus, the keyed gate is opened once each 16.6 ms and will pass only a small portion of the 60 Hz reference signal. This short sample is stored on a reference capacitor which is isolated by a very high impedance emitter-follower circuit. The signal on the reference capacitor is then used to control a multivibrator for the next 16 ms. Depending upon the amplitude of the 60 Hz reference signal during the sampling period, the 31.5 kHz multivibrator will speed up or slow down. When the frequency and phase of the internal vertical trigger and the reference 60 Hz signal are in synchronism, the voltage on the reference keyed capacitor circuit will remain constant at the reference frequency. The multivibrator is buffered by additional gating circuits and then sent throughout the system when the crystal oscillator is not being selected.

2.6.3.3 525 Countdown Board (8661-A5). The countdown board is composed of a 10-stage ripple-through counter and controls SN7400 type gates. The 2H signal coming from the 8661-A8 board is fed into the clock terminals of the first flip-flop of the counter. This counter is a ripple-through type counter with the next stage changing each time the previous change stage goes from a high to a low condition. The initial state of the counter is such that all outputs are low. At the 513th 2H pulse, the stage of the last flip-flop goes from a low to

a high condition. This initiates the horizontal blanking period. Logic circuits in the form of gates and other flip-flops cause all flip-flops to go low after the 525th pulse and this is the state that exists at the 526th pulse. Thus the counter completes one full cycle every 525 pulses.

2.6.3.4 Sync and Blanking Generator (8661-A6). This board provides all the synchronizing pulses utilized in the system except for some signals generated in the SEC vidicon camera. Generated on this board are vertical blanking, vertical sync delay, vertical sync, horizontal blanking, horizontal sync delay, and horizontal sync. The two inputs of this board are the vertical trigger in and the horizontal trigger in, both signals coming from the countdown board. The logic components are SN7402 NOR gates. The operation of the circuits on this board are similar in that a number of one-shot multivibrators are utilized to generate all of the required pulses. The leading edge of the incoming pulse tends to trigger the multivibrator gates which stay on for an adjustable period. The gate then recovers and goes back to its quiescent level. As a result, the various pulses are produced from the two trigger pulses through a number of microcircuit gates. The pulses are mixed to provide the necessary mixed blanking and mixed sync outputs. It should be stressed that NOR gates are used rather than monostable microcircuits.

2.6.3.5 Grey Shades Counter (8661-A2). The grey shades generator is supplied to provide a signal source for setting up the video

processor and for use throughout the system. Three boards (A2, A3 and A4) make up the grey shades generator. The grey shades counter board has two inputs: the 2H signal and the vertical blanking. Outgoing signals include a signal from each of the binary counting elements in the ripple-through counter. The 2H signal acts as a clock and the binary counters change state when the next least significant count goes from a high to low level. A total of six lines pass out of the A2 board to the A3 board, known as the ladder board. The ripple-through counter is reset by the vertical drive pulse and starts counting at the end of each vertical blanking period.

2.6.3.6 Grey Shades Ladder Boards (8661-A3). The purpose of the grey shades ladder boards is to take the seven high and low signal inputs from the A2 board and to weigh them in such a manner as to provide a uniform stepping function in synchronism with one-half the horizontal line rate. This is accomplished by a ladder network which properly weighs the flip-flop signals with respect to the significance of the source to provide a uniform analog change of almost 120 different states. The ladder is controlled by the state of saturated transistors in the circuit. The bases of each of the control transistors is driven by one of the input signals from the A2 board. The emitter of each of these transistors passes through a control switch located on the front of the assembly and then to ground. Thus, if the control switch is in a position that grounds the transistor, the transistor will saturate each time

that the input signal is at a high level. The ladder network is a resistor combination which just doubles the effect of each more significant bit binary input signal. The output signal after the end of vertical drive starts to increase at a uniform rate in synchronism with one-half the horizontal line rate. This signal is fed to the A4 board.

2.6.3.7 Shades of Grey Sync Mixer (8661-A4). This board accepts the video output of the grey shades ladder network (8661-A3) and proceeds to add sync and blanking signal to provide a composite video signal capable of being utilized throughout the system. The input video is first amplified and clamped to a selectable level. The black level of the composite video is established by a clamping circuit keyed during the blanking period. The sync tip level is established by a second clamping signal keyed only during the sync period. Thus, the final signal is composed of the video signal with a black level and a sync tip level added. This signal is amplified and fed into a 75 ohm terminated line. This test signal can be utilized throughout the system.

2.6.3.8 Disc Recorder Pulse Generator (8661-A1). The disc recorder requires some reference sync and control signals to operate properly in the system. The A1 board converts the horizontal and vertical sync pulses into forms which can be utilized by the synchronizing circuits of the disc recorder. In addition, the disc recorder requires control signals which will select the track for recording the new data and also provides the control signal for the period in which data is actually being written.

The appropriate timing signals are initiated by the vertical drive pulse and the 2H signal. Since these signals require slight modification, gating circuitry together with one-shot multivibrators are utilized to provide the exact form required by the disc recorder. The 2H signal is made to be approximately 16 ms in the high condition and approximately 15.2 ms in the low condition. The N reference occurring once per field is approximately 16 ms high and is in synchronism with the 2H reference signal. A control signal selects either the A or B channels on the disc recorder to be read. While one channel is being read, there is a capability of writing on the other channel; however, a third control signal, the write line, must be high. In the event the write signal line is not high, the information on the disc will continue to read out alternately. It should be pointed out that normally a write signal leads to the destruction of the previously stored data. Since the disc recorder will also be utilized to read only a single frame from the SEC vidicon in the integration/storage mode, board A1 will accept a trigger pulse which determines the period in which the SEC vidicon camera is supplied a composite signal out. As a result, this signal is processed on the A1 board and utilized for control of the disc recorder recording or writing sections.

2.6.4 Video Processor.

2.6.4.1 Video Amplifier. (8661-B1). The video amplifier first strips the sync tips from the input composite video being sent

into the processor and amplifies the video information by an external controllable gain stage which can be varied from approximately a gain of 2 to a gain of 10. A total of two feedback amplifiers are utilized in this circuit with the gain of the first amplifier being set at approximately 3 and a gain of the second amplifier being adjustable.

2.6.4.2 Level Selector (8661-B2). The purpose of the level selector circuitry is to take a selectable 1.2V segment out of the amplified video signal, which may be as large as 11 to 12 Vpp. The incoming video signal is passed through some isolation buffers and then into a dc restoration circuit which establishes a constant black level throughout the field. This is important since the clipping level will essentially be a dc adjustment. Two back-to-back diodes have the output of this clamped signal tied to the center point. The diodes themselves are attached to a large capacitor which may have its bias voltage varied. Any signal voltage above or below the threshold voltage to turn the diodes on, approximately 0.7V difference from the capacitor reference, will be shunted to the large capacitor. Since the reference capacitor voltage can be varied by a control located on the console panel, any level of the incoming video signal voltage can be passed through this circuit to an output buffer while all the other levels are shunted to the large capacitor.

2.6.4.3 Vertical and Horizontal Syncs (8661-B3). The vertical and horizontal signals are used in many circuits in the video processor.

A special circuit provides a low-impedance output source for these signals. These circuits are composed of a ground-emitter amplifier and buffers.

2.6.4.4 Video Mixer (8661-B4). The video mixer allows the substitution of the processed video signal for the unprocessed video signal in the output video at times selected by the operator. The composite output is a controlled combination of both videos. An important performance factor is the matching of white and black levels of the two video signals. Thus, the video mixer, under control of other circuitry, decides whether the processed or unprocessed video shall be delivered to the buffered output. In addition, the black levels can be mixed and some of the gains can be adjusted, so that both signals are equal. The only difference is that the processed signal has been amplified and a specific level selected. The output of this board is fed through an emitter-follower back into the case harness.

2.6.4.5 Reverse Video and Gate (8661-B5). This board has a two-fold purpose; to reverse the video levels so that normal black signal voltages become white voltages and normal white signal voltages become black, and to generate the P and $\bar{P}$ pulses required for selecting the appropriate processed and unprocessed video to be transmitted.

For video signal reversal, the mixed video from board 8661-B4 is fed into a direct-coupled phase reversal amplifier. This amplifier feeds a buffer or emitter-follower stage. Note that

the high-level whites have now been converted to blacks and after passing through the buffer, the reversed signal is now clamped so that a black level is established. This clamping operation is necessary to correctly establish the blanking level. Remember that the input signal black level is now at peak white; this is the point that the clamp is setting the signal level. A second ground clamp circuit resets a correct black level during blanking. This output video signal is reversed except during blanking. After the keyed blanking white level has been established, the output is buffered and sent to a control panel switch which allows selection of the normal mixed video or reversed mixed video.

The P and $\bar{P}$ pulses are essentially pulses which control circuitry in the video processor and determine when the processed signal is used and when the unprocessed signal is used. The actual determination is made by two one-shot multivibrators which are triggered either once each horizontal line or once each vertical field. When both of these multivibrators are triggered, the P pulse is initiated by a series of NAND gates and a transistorized driver. Thus the processed window, which is seen on the display, is either a rectangle or square. It is generated by the mixing of these two one-shot multivibrator signals. This mixing is done on board 8661-B5.

2.6.4.6 Sync Mixing (8661-B6). The sync mixer board (8661-B6) receives the composite video from either the video mixer or the video reversal boards. The timing pulses required to provide

a composite video signal output are then added on this board. The input video signal enters through an emitter-follower isolator circuit whose output is sent through a capacitor and then a keyed clamped circuit. This keyed clamped circuit establishes the black level for the final output signal. During the sync period a second transistor is saturated, going to a preset voltage level below the black level and establishing the sync tip level. Thus during the blanking and/or sync period the output video is established by voltage levels on capacitors and saturated transistors. During the active video period, the path is established between the input and the output driver. The combination provides the composite video needed for the output.

2.6.4.7 Horizontal Oscillator (8661-B7). A keyed horizontal multivibrator is provided to trigger the horizontal window gating. In the event of a loss of sync, this multivibrator will free-run. When keyed, this will provide a synchronized horizontal gating period.

2.6.4.8 Horizontal Window (8661-B8). The horizontal window circuitry selects the horizontal time period in which to display the processed video. Since the window boundaries can be seen on the monitor, the operator has the capability, by varying panel-mounted controls, of adjusting the position of the width of the window. A trigger pulse received from the horizontal oscillator is used to energize a one-shot multivibrator. Now the one-shot multivibrator resets at the end of its adjustable cycle; however, the horizontal sync pulses are utilized to re-

this multivibrator when and if it has not reset during the active period. It should be noted that the leading edge of the horizontal window is selected by controls on the panel and the width of the window is selected by a second control. For each horizontal line, both multivibrators can be triggered., resulting in the generation of the window. Similar circuitry exists for the vertical portion of the window and, except for the time constants, is directly controllable from the front in which the beginning of the vertical window and the height of the window can be established by the operator.

2.6.4.9 Vertical Oscillator (8661-B9). The vertical oscillator provides a synchronized gated signal that provides the vertical references in the video processor. The operation, except for time constants, is identical to that described in the horizontal oscillator (paragraph 2.6.4.7).

2.6.4.10 Vertical Window Generator (8661-B10). The vertical window generator provides the uppermost beginning of the window and also the height of the window. Its operation, except for time constants, is identical to that of the horizontal window generator described in paragraph 2.4.6.8.

2.6.5 SEC vidicon Camera. The SEC vidicon camera is a modified STV/614 Westinghouse SEC vidicon unit. The modifications in this unit include bringing the SEC vidicon forward in its mounting assembly, and modifying the wiring at the rear of the case to allow the readout pulse, during the integration mode, to be taken off the connector in the rear. Finally, two of

the drive connectors in the rear are modified to accept incoming horizontal and vertical drive pulses. In a normal operation in the Neutron Radiographic Viewing System, boards 7703 and 7704 should be removed from the system. For the theory of operation of this system, see the Westinghouse manual on this camera.

2.6.6 Video Disc Recorder. The video disc recorder utilized in this system was custom-fabricated for Zenith Radio Corporation by Data Disc, Inc. See the Data Disc manuals on this recorder for theory of operation and troubleshooting.

2.6.7 Monitor. The Conrac Model CQC-17 television monitor utilized in this system has been supplied as Government-furnished equipment. Your attention is directed to the standard Conrac monitor manual for the model CQC-17.

2.6.8 Power Supplies. The power supplies utilized for -16V, +7V and +16V are standard Power-Mate power supplies (Models RC-15 and RB8-30). Your attention is directed to the Power-Mate manual supplied with this equipment.

3. DESCRIPTION OF DEVELOPMENT

This section describes the design evolution of the system. Included are initial concepts, "blind alleys", and problem areas, all leading to the final design.

3.1. Proposed System

The Neutron Radiographic Viewing System originally proposed by Zenith was as follows. The basic units of the proposed system are shown in the block diagram of Figure 3-1. The thermal neutron source and the specimen were to be supplied by NASA. The converter screen, lens, SEC vidicon, long-term storage device, video processor, and display were to be either purchased or fabricated by Zenith, or modified GFE equipment supplied by NASA and modified by Zenith. The conversion of thermal neutrons to light was to be through a special screen based on a lithium six-tritium conversion principle. The gain of this screen was to be 10,000 photons for each neutron converter. Efficiencies were expected to be as high as 30 percent. A group of lenses to be supplied for this system were to be of commercial quality unless the results of the study phase indicated the economy of using special radiation-resistant glass. The SEC vidicon, type 31189 or equivalent matched with an image amplifier, was to incorporate a fiber-optic-coupled image intensifier/SEC vidicon package. Scan conversion was to be provided either by a GFE ITT industrial scan converter system, if practical, or by a video disc storage system. The video processor contains electronic circuits fabricated by

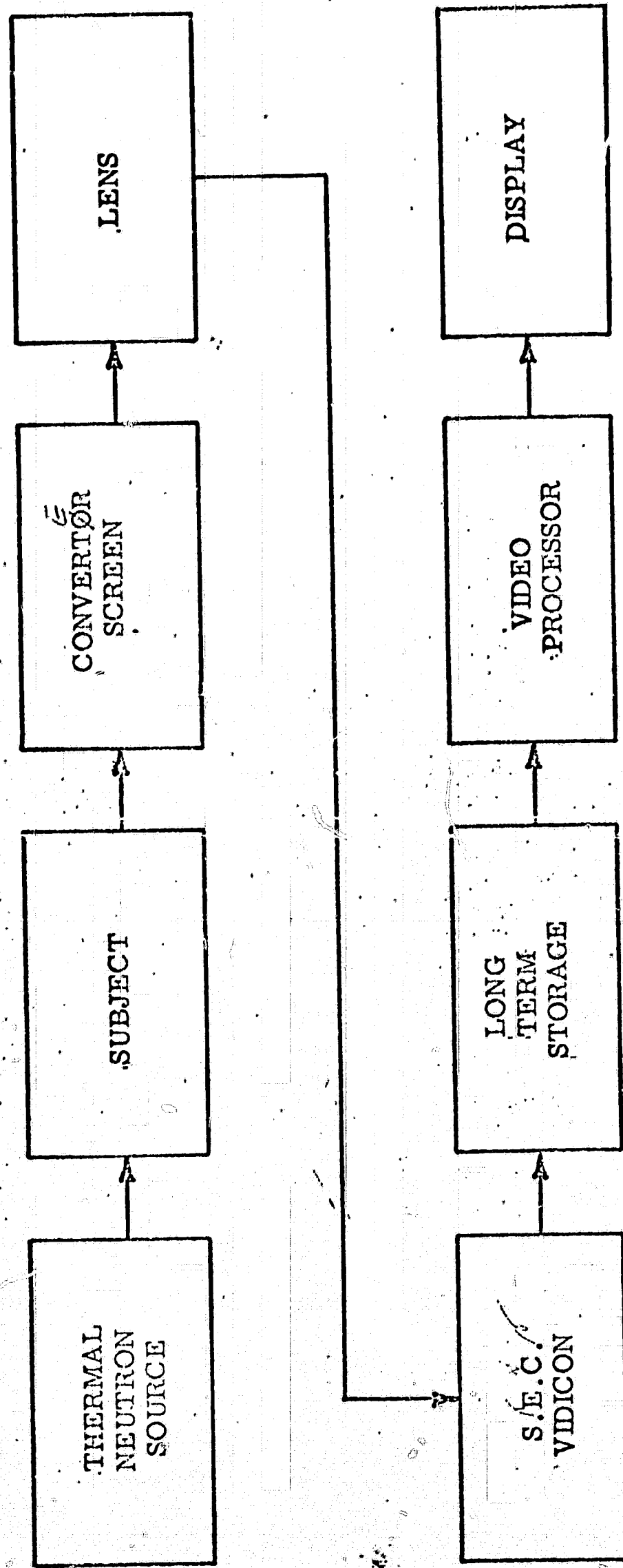


Figure 3-1. Proposed System Block Diagram

Zenith and was to be used to meet the contrast specification. The display unit was to be the GFE monitor.

The sequence of events in the operation of the proposed system were as follows: The object to be radiographed is submitted to a radiographer; the radiographer evaluates the specimen's characteristics, including the basic materials, physical shape, etc., and then determines the lens and the screen distance to be utilized to obtain the best results. The operator places the subject between the source of neutrons and the converter screen in the orientation required to view it. At this point, the operator leaves the immediate area of high radiation fields and goes back to the radiographic control console which is positioned near the controls for the thermal neutron source.

After allowing a warm-up cycle for the SEC vidicon camera and the thermal neutron source, the operator uses at least one or two of the following approaches to obtain the neutron radiograph. The first is to adjust the equipment for a specific storage time cycle and select a single frame readout. After turning on the thermal neutron source and ascertaining that it is up to the desired flux level, the operator initiates the storage cycle. After a pre-timed storage cycle, the data is automatically read from the SEC target area to the long-term storage or scan conversion device. The output is then viewed after passing through the video processor.

If the ITT industrial slow scan converter system is utilized, it may be necessary to add a tape recorder to provide long term storage.

The second approach, if a video disc system is supplied, would allow the SEC vidicon to store the neutron image for a short period of time and then to transfer the information to the disc and a display. The operator can then elect to run a second storage cycle (whose output can be added with the first storage cycle output) to the video disc recorder, which can continue to supply video information to the display without destruction of this information. To improve the signal-to-noise ratio, the operator can read out the contents of an additional storage cycle. The signal information of the radiograph can be expected to be directly additive, while the statistical noise, including the tube noise and thermal neutron variation, can be expected to increase as the square root of the sum of the squares of their value. As a result, the signal will grow more rapidly than the noise.

3.2 Design Considerations

3.2.1 GFE Equipment. The following GFE equipment was to have been made available for use and/or modification on the program.

- a. Vidicon camera manufactured by General Precision Laboratory (Reference G-5381).
- b. Camera remote control unit manufactured by Conrac Division.
- c. Television monitor manufactured by Conrac Division, Model CQC-17.

d. Scan/playback subsystem manufactured by International Telephone and Telegraph Co., Fort Wayne, Indiana (NASA Contract NASA-11942).

Further information from NASA indicated that the GPL vidicon camera took standard 6" vidicon tubes such as the 7735 type and had a bandwidth of 12 MHz, allowing resolutions of up to 8 MHz. The basic scan rate could be operated at either 525 lines or 675 lines, depending upon the user. The monitors, conventional Conrac monitors, would be compatible with the vidicon camera, and the scan/playback unit. The scan/playback unit, manufactured by ITT, basically used the storage tube principle system.

After an engineering evaluation of the GPL vidicon camera and comparing its capabilities with the system requirements in the scope of work, it appeared that a modification of this camera would be less advantageous than for the Government to purchase a new SEC vidicon camera. The reasons are as follows: The SEC vidicon would require a different mechanical mounting and power supply voltages up to 7.5 kV. A different yoke assembly would probably also be required. The video amplifier of the standard SEC vidicon is roughly 7.5 MHz rather than the 12 MHz in the GPL unit, because of the noise problems associated with the SEC vidicon output. In addition, the standard SEC vidicon already had the capability of selectable single frame readouts which could be varied from 30 frames per second through a range of one frame every 70 seconds. Readout rates slower

than this could be generated by external equipment. Next, the size of the SEC vidicon, together with the required image intensifier tube, which would take an additional 13 to 15 kV power supply, would require extensive mechanical redesign of the GPL camera. Finally, the re-layout of this case would require extensive rewiring of the present GPL camera case. Because of these factors, Zenith did not propose modification of the GPL vidicon camera system, and very little, if any, of this unit would be utilized. The GFE television monitor, on the other hand would be utilized as it exists, provided its line rate is compatible with the performance required by the present specification. The scan/playback system appeared to be feasible for a limited period of data display. The characteristics information on the scan/playback system were not available to Zenith at this time; however, the ITT system contained a scan converter tube whose output should be degraded with the readout time. Because of this characteristic, an alternate method of providing scan conversion and playback storage was also offered.

3.2.2 Converter Screen. The size of the converter was determined by the scope of work and the faceplate of the image intensifier used in front of the SEC vidicon. The commercial version of the image amplifier (WX-30677) has a 40 mm faceplate, which means that at a minimum 1:1 ratio, the diagonal of the converter screen is 1.57 inches with a width of 1.26 inches and a height of 0.94 inches. With a 10:1 ratio increase, the screen size

becomes 12.6 inches in width by 9.4 inches in height.

This conversion screen was to be composed of ${}^6\text{LiF}$ and ZnS (Ag) with the enrichment in ${}^6\text{Li}$ about 95 percent. The responsible neutron conversion nuclear reaction is ${}^6\text{Li} + {}^1_0\text{n} \rightarrow {}^3_1\text{H} + {}^4_2\text{He} + 4.8 \text{ MeV}$. The resulting charge particles cause scintillations in the ZnS (Ag) phosphor. The light output of the screen was to be maximized: approximately 10^4 photons per absorbed neutron. The resolution of the screen is approximately inversely proportional to the neutron absorption of the screen. At 150 lp/inch resolution, the screen was to absorb approximately 20 percent of the incident thermal neutrons. The scintillation decay time to 10% is less than 1 millisecond. The nuclear reaction induced by the neutron is essentially clean, and no measurable residual radioactivity should be observed after each use. The depletion rate of the neutron converting material at the flux rate of $10^7 \text{ N/cm}^2/\text{sec}$ is practically unlimited. The screen was to be deposited on a thin, stiff, supportive material which should have very low neutron absorption and scattering characteristics, typically aluminum.

Testing of individual screens as well as the whole system was to be performed in a preliminary manner with X-rays at approximately 80 kV of energy. The testing essentially consists of resolution measurements. The neutron absorption characteristics of the screens were also to be tested with a low-intensity neutron source.

3.2.3 Optics. The scope of work required an object size variation

from 0.94" to 9.4" in height. This required an object-to-image size range of variation ratio from 1:1 to 10:1. The conservation of light is extremely important in this system and careful design of the optics was required. A basic formula for predicting the light attenuation effects of a lens is:

$$\frac{I_o}{I_{in}} = \frac{t}{4f^2(1+m)^2}$$

where: I_o = light intensity in
 t = transmissivity of lens
 f = f-stop of lens
 m = magnification of lens.

Note that the magnification and f-stop of the lens are the most important contributors to the ratio of output-to-input light intensities. The f-stop is defined as the lens focal length divided by the effective objective lens diameter. Since the cost increases rapidly for a small f-stop lens with increasing focal lengths, it was advantageous to keep the lens focal length reasonably short. In addition, the object-to-lens distance for a long focal length lens at the 10:1 object-to-image size ratio will become quite large. For the magnification range varying from 0.1 to 0.3, a lens with a 30 mm focal length was proposed.

The approximate lens-to-screen distance for a 0.1 magnification is 12 inches while the distance for a 0.3 magnification is 4 inches. The insertion loss of the lens was expected to be

0.078 for a magnification of 0.3. For a magnification of 1.0, the transmission becomes 0.026 for a single lens system, which is unacceptable.

These figures were obtained from the equation by using an "f" of 1.5 and a "t" of 0.85. For a magnification of 1.0, a two-lens system was suggested as shown in Figure 3-2. The two-lens approach allows up to 0.08 of the input light to be transmitted.

The object (screen) was to be located at the first focal point of the collimator lens (a) and all light rays passing through the collimating lens to be parallel. The imaging lens then collects these rays and focuses them at its second focal point, the location of the image intensifier photocathode.

3.2.4 Image Intensifier-SEC Vidicon Package. The scope of work specified that a Westinghouse SEC tube (type 31189) plus image amplifier or equivalent would be provided. For reasons indicated in paragraph 3.2.1, Zenith proposed to purchase a modified Westinghouse STV/614 SEC camera. This equipment would be incorporated into both the camera housing and the control console. One important consideration was to be the anticipated performance of the system under typical operating conditions. Starting with the SEC vidicon, the data sheets for the WL-30691 indicated that TV line resolution can be anticipated with a photocathode illumination level of 0.02 foot-candles with a frame rate of 1/30 second. The gain of a WX-30677 image intensifier is specified as being 200 minimum, and assuming a transmission of

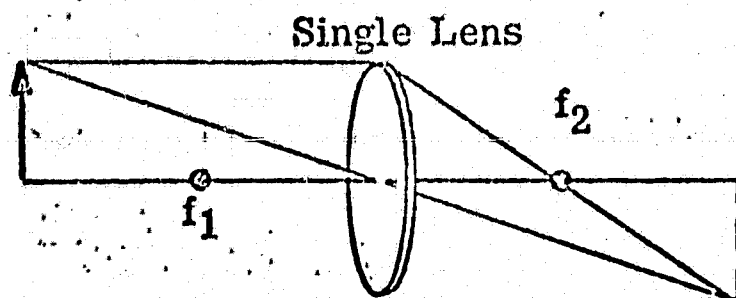
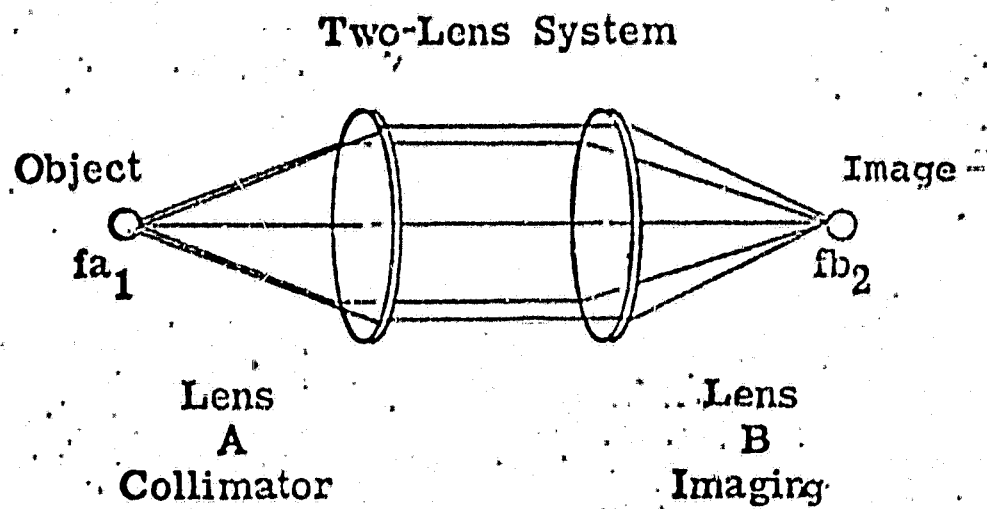


Figure 3-2. Single and Two-Lens Systems

0.5 for the fiber optics, the package could be expected to deliver 600 lines resolution, with highlight levels of 2×10^{-4} foot-candles on the faceplate of the image intensifier tube. Since there are approximately 3×10^{16} photons/lumen/sec in white light when uniformly illuminated, there are:

$$\frac{3 \times 10^{16} (2 \times 10^{-4})}{30 (12 \times 2.54)^2} = \frac{2 \times 10^{11}}{930} = 2.15 \times 10^8 \text{ photons/cm}^2$$

required to obtain 600 TV lines resolution. For a system having a magnification of 1.0, the lens transmits up to 0.08 percent of the light seen at the converter screen. The screen itself is assumed to provide 10^4 photons per conversion and to have 20 percent conversion efficiency. With a flux of 10^5 neutron/cm², the anticipated time to obtain the 600-line resolution from the intensifier SEC system becomes:

$$T = \frac{N_p}{(N_t) (P) (E) (l)} = \frac{2.15 \times 10^8}{(10^5) (10^4) (0.2) (0.08)} = 13.4 \text{ sec.}$$

where: N_p = number of photons/cm required at faceplate of tube

N_t = neutrons/cm²/sec flux

P = photons per conversion

E = efficiency of conversion

t = time

l = lens transmission

Since this time is well under the time required for 0.010-mil resolutions due to quantum effects, it is apparent that the system has sufficient gain. The magnification of a "1" system has an image height of 24 mm. The proposed screen was to have

a resolution of 150 lp/inch, while the lens was to have center resolutions in excess of 1900 lp/inch. The intensifier/SEC vidicon combination was to have a possible resolution of 300 lp/inch on the vertical of the intensifier photocathode. The expected resolution was:

$$\frac{1}{R_t^2} = \frac{1}{R^2} = \frac{1}{(150)^2} + \frac{1}{(300)^2} + \frac{1}{(1900)^2}$$

$$R_t = 133 \text{ lp/inch}$$

This appeared more than enough for the desired resolution of 0.010 holes.

The only noise mentioned to this point in the discussion has been quantum noise. Possible noise sources included the converter screen, gamma and other types of radiation, image intensifier, SEC vidicon tube during both storage and readout cycles, and SEC vidicon camera electronic amplifying circuits. Preliminary calculations indicated that the image intensifier could prove the worst source of noise in the system, and that a special low-noise unit might be required for long integration periods. This problem was to be investigated fully during the System Analysis and Design Phase. After a preset storage cycle, the target of the SEC vidicon tube was to be scanned and a single frame of composite video sent from the camera to the scan conversion unit. The STV/614 camera had the capability of providing either a 2:1 interlace or a single frame readout. The type of readout was to depend somewhat on the device used as a scan converter.

3.2.5 Scan Converter. The single frame readout from the SEC vidicon cannot be studied by a human observer. Thus, a device to present the data for a much longer period of time was required. The GFE scan/playback subsystem appeared to accomplish this and was proposed for this system. NASA advised Zenith that the device was a tube-type scan converter system. The single frame of input video data is written on a storage surface which has a long decay time constant. This surface is either optically or electronically scanned, not necessarily at the input scanning rates, and generates a composite video. Storage times from a few seconds to several minutes were obtained from equipments of similar design. NASA indicated that this sub-unit had sufficient storage, bandwidth, and shades of grey performance to meet all specifications for scan conversion in this system.

3.2.6 Alternate Scan Converter. The storage tube-type scan converter system suffers from several problems such as destructive readout leading to a limited playback period, loss in grey shades, and additional noise and shading effects. In addition, data processing at the storage tube is not easily accomplished. Because of these deficiencies, Zenith offered an optional alternate approach to the problem in the form of a combined storage period and data processing magnetic disc scan conversion system. The incoming video is stored on one channel of a magnetic disc which also provides the system synchronizing pulses. The video may then be read out as many

times as desired since the readout process is nondestructive. Although rarely done, a change in scan rates could be obtained by changing the rotational frequency of the disc. Standard broadcast quality video with over 6.0 MHz bandwidths are now readily available.

Figure 3-3 shows the basic components of the proposed disc storage system. The write amplifier accepts the single frame composite video from the SEC camera and stores the information on the appropriate channel selected by the master controller. The video-in channel storage is then read out by the "read" head and amplified. The output of the read amplifier is added, if so desired by the operator, to the output of other channels and then sent to a sync mixer where the output composite video is generated. This video can then be displayed or processed by the contrast enhancement circuitry.

The advantage of the multi-channel storage approach can be appreciated when it is realized that fixed signal amplitudes such as the neutron radiograph are directly additive, while a great many random noise signals increase only as the square root of the sum of the squares. This system then gives a method of increasing the signal-to-noise ratio of the composite video by taking a number of short neutron radiographs instead of one. In addition, one disc channel can store the shading and imperfection signature of the SEC tube, image intensifier, and converter screen. This signal can then be reversed electronically and added to the other data signals, greatly

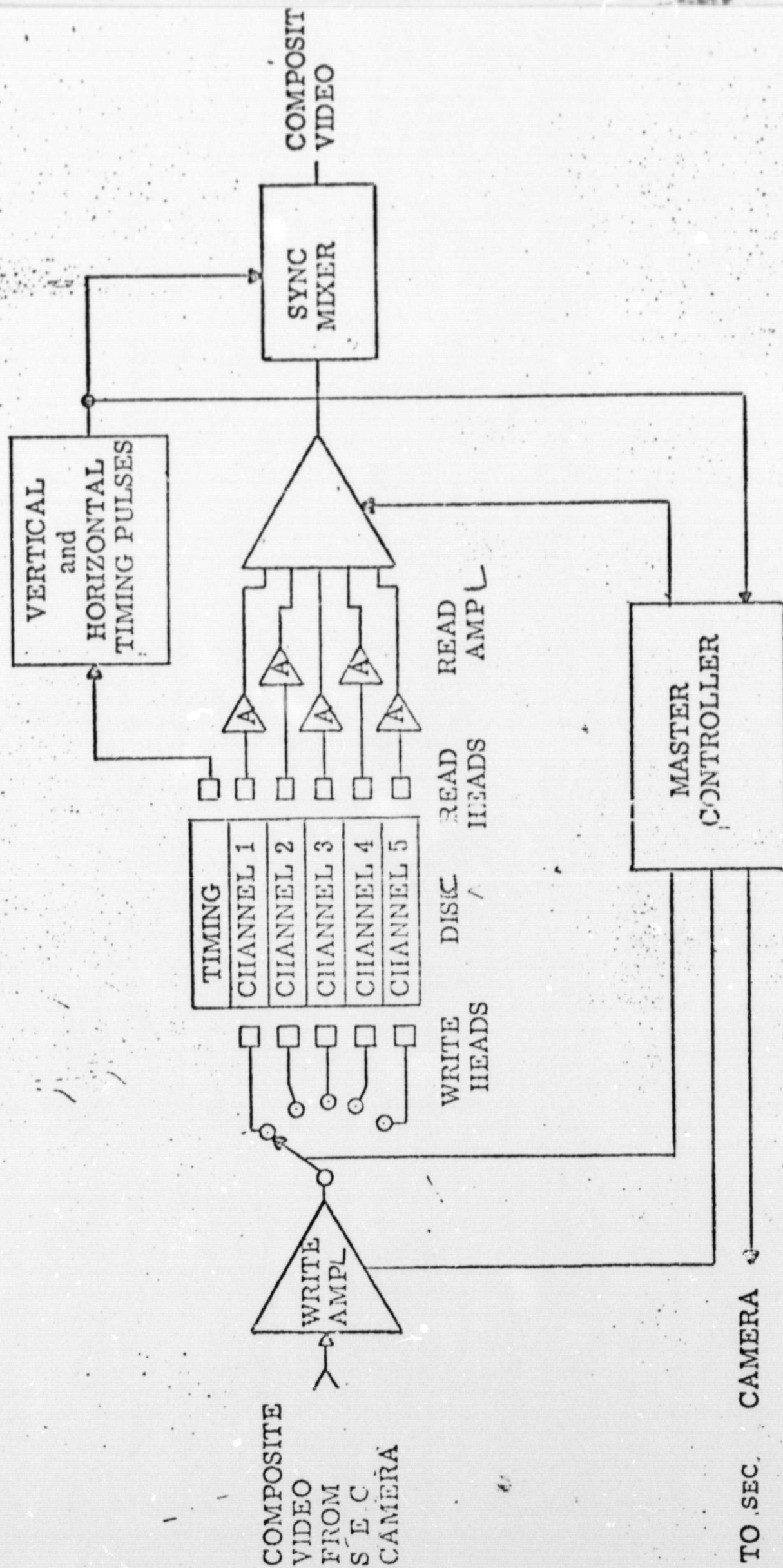


FIGURE 3-3. Disc Storage System

improving the quality of the image. Since the readout is nondestructive, the operator has time to examine the radiographic image, and investigate the effects of contrast enhancement video processing. The system operation with disc storage would be as follows:

- a. The operator selects the SEC target storage cycle period and the number of disc channels to be used. (A total of five storage channels were proposed.)
- b. Upon initiation of the radiographic cycle, the SEC vidicon target starts to accumulate the neutron radiographic image, all disc storage channels are erased, and the input composite video path to the recorder is set up for the first channel.
- c. Upon completing the first SEC target storage period, single frame readout of the target is initiated by the master controller. Note that all synchronization of sweep signals in the system comes from the disc timing circuits.
- d. Upon completion of the first readout cycle, the SEC target starts to accumulate data from the second cycle. The input composite video path is changed from the first to the second disc channel. The contents of the first channel are now available for immediate viewing.
- e. This process is continued until all channels selected by the operator contain inputs from the SEC vidicon camera.

3.2.7 Contrast Enhancement. It was assumed that the arbitrary portion of the raster to be selected for video processing could be rectangular in shape. A simple counter would then be associated with both the horizontal and vertical scanning rates (see Figure 3-4). With logic gates, a preselected count on each axis would generate a gate pulse for the area selected. Assume that 1% control of the area is desirable. Two decades (100 counts) would be necessary for the horizontal, and the same amount for the vertical. A switch which selects a decoding gate would then be set to determine the start of the area and another to determine the end of the processed area. The same procedure would be accomplished in the other axis. Gate signals would be generated to control the processing of the data in this area on each scan and would continue to do so until the system is shut off or until the boundaries are changed.

Because of the great variety and low cost of presently available integrated circuits, this system could be implemented at lowest cost. This system would also be very reliable and require virtually no maintenance because of its almost total dependence on logic circuits.

After the gate pulses have been generated, the video processing is somewhat more difficult in that analog gates must be used. Since the processed signal must appear with unprocessed video, a great deal of attention must be paid to the dc stability of the circuits used in processing. Bandwidth must be maintained, not only in the video circuits, but also in the analog gates so that switching transients and loss of data can be minimized. Two basic operations are involved: first, changing the gain and/or dc positioning of the processed sector of the video line, and sec-

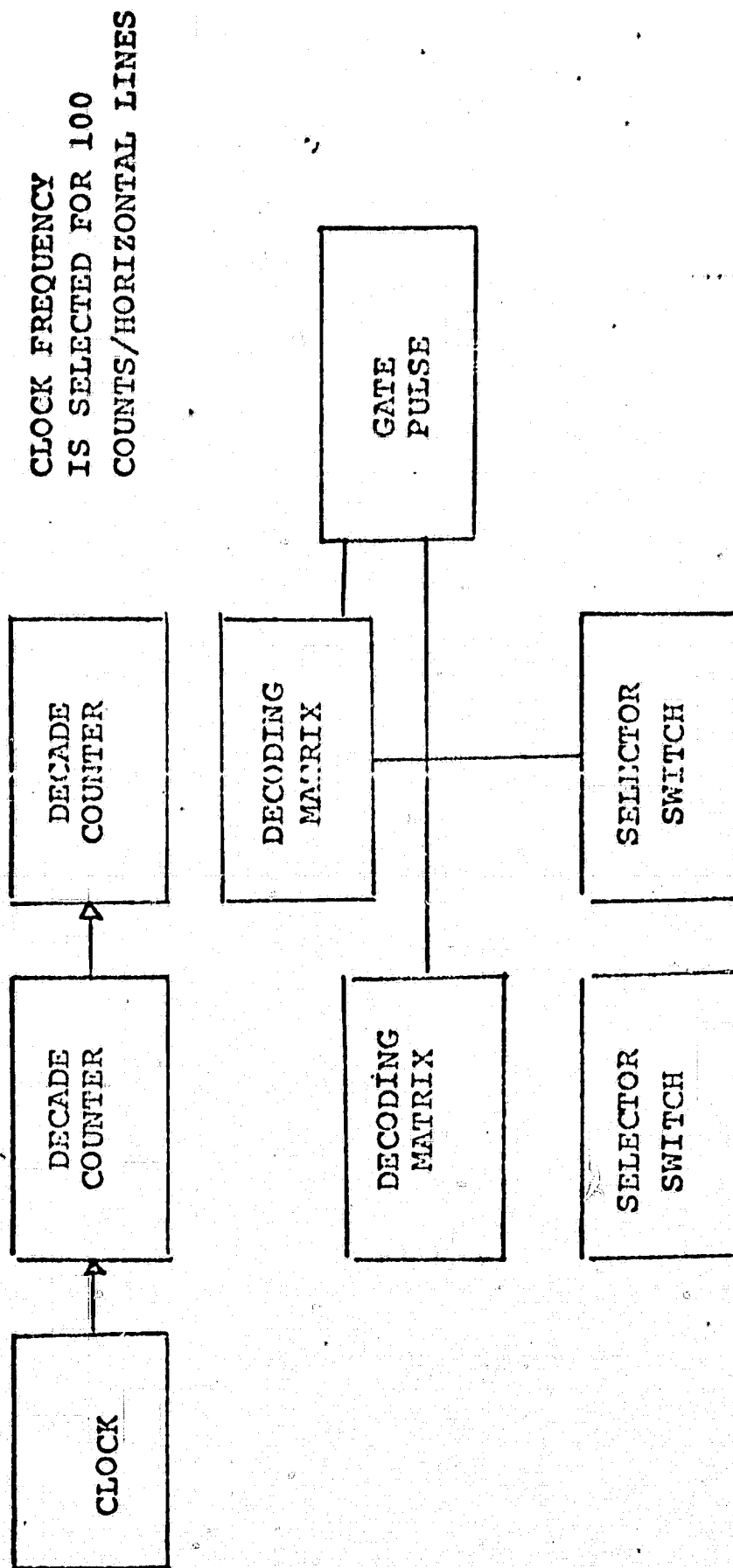


Figure 3-4 Gate Generator Circuitry Block Diagram

ond, expanding a selected range of grey to full-scale video.

The first is accomplished quite readily since it involves two amplifiers, one of which is gated on when the other is gated off. One of these requires gain and level controls. The second requires a little more circuit technology in that an infinite clipper with adjustable level must be used. The remaining signal must then be amplified so that full-range video is available. This signal must also be gated through the analog gates so that it can be observed in the selected sector along with the unprocessed video.

It was planned to use integrated circuit operational amplifiers such as the Fairchild 709 for most of the video processing. Good bandwidth could be obtained with these devices even with gating. A functional block diagram of this discussion is shown in Figure 3-5.

3.2.8 Monitor. It appeared that the GFE Conrac Model CQC-17 monitor would be satisfactory for the system.

3.2.9 Mechanical Considerations. The proposed system was to be contained in two units (Figure 3-2 shows an artist's concept of the system). If space was limited, a vertical rack would be supplied. The intensifier SEC vidicon camera was to be clamped in a metal frame attached to a GFE wheeled tripod or other type of support. The metal frame was to be connected to four tubular rods with linear motion assemblies. The camera was to be attached to a bellows with a light-tight seal, while the scintillator screen would be attached to a pure aluminum or other low-neutron-absorbing material protective shield. The front of the bellows would be attached to the protective shield which would be supported by bearing riding-on rods attached to the frame supporting the camera. The bellows could be varied over a range of 12 inches, allowing

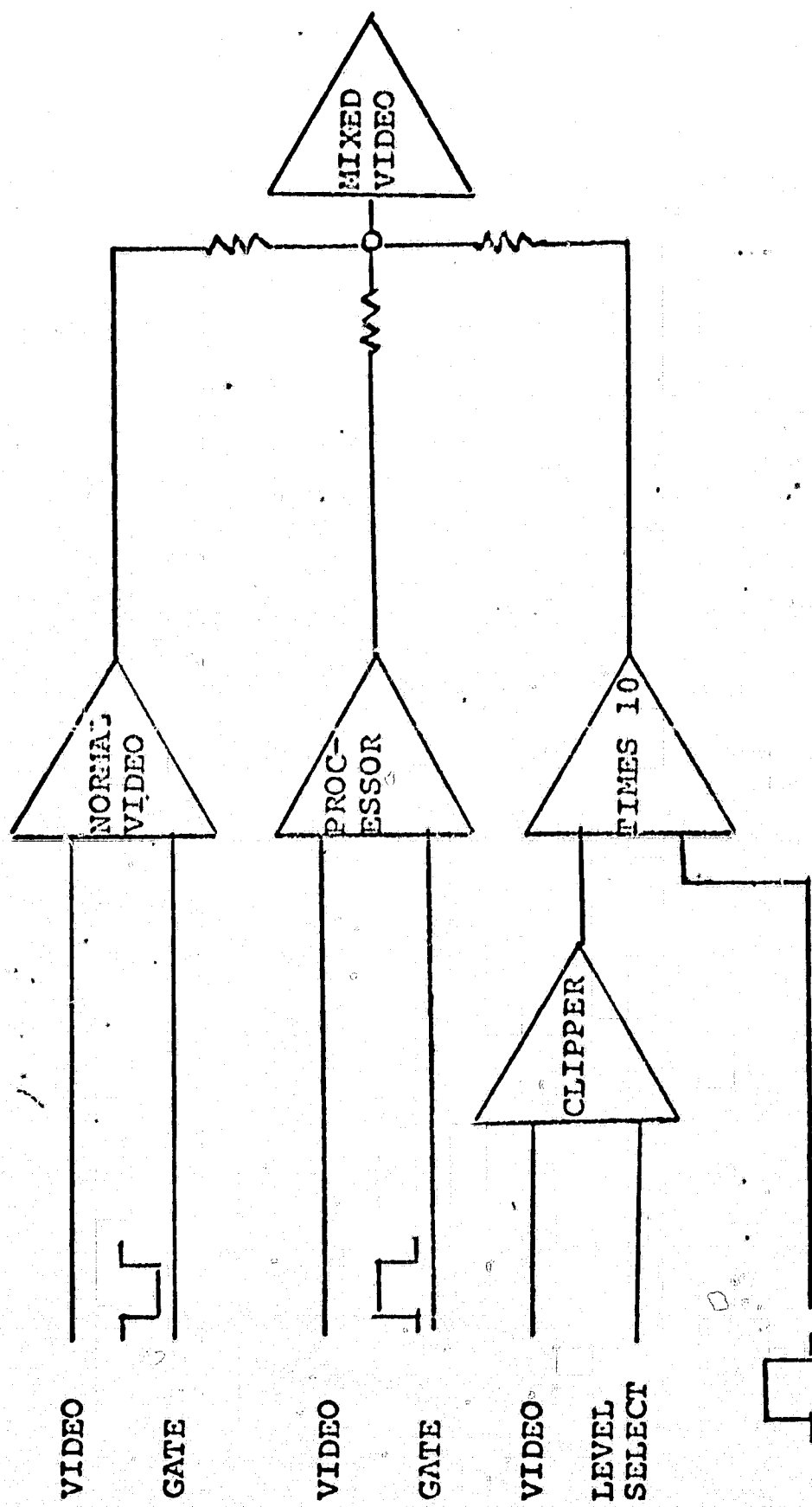


Figure 3-5. Contrast Enhancement Circuit Block Diagram.

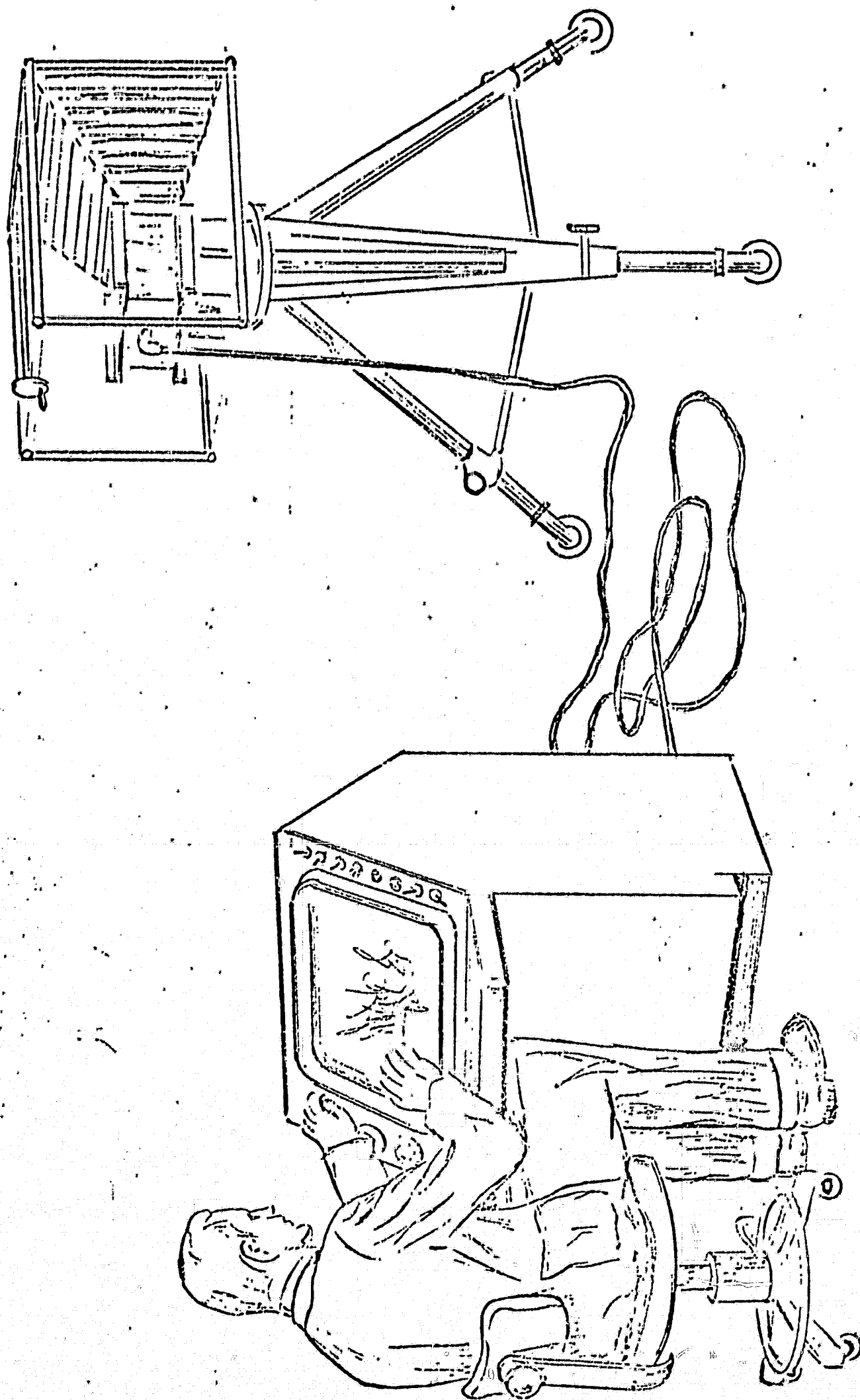


Figure 3-6. Artist's Conception of CCTV Neutron Viewing Conversion System

the set-up of a range of magnifications from 0.3 to 0.1. The camera, screen, and bellows assembly would contain a microswitch which opened the input power circuits wherever the possibility of a light leak to the intensifier/SEC tube existed. The proposed lens would be changed and adjusted at the camera, although, if later required, a remote lens selector and focus-adjust system option could be added. A control cable of at least 75 feet length would be provided with the system. The control console would contain the monitor, intensifier/SEC control unit, scan converter unit and gate processing circuitry. The bulk of this electronic circuitry would be contained under the operator's table, with only the display and essential operator's controls located above the table.

3.2.10 Change to Scope of Work. Zenith proposed the following change to the specification: a. Paragraph 3.1 of Exhibit "A" specified that the converter screen shall have a minimum resolution of 600 TV lines per inch. Tests conducted at the Rauland Division of Zenith showed an increase in neutron conversion efficiency with an increase in scintillation film thickness. However, a thicker film also leads to a poorer screen resolution figure. Since the efficiency of the system in light amplification has only a small safety factor, Zenith could not at that time guarantee a scintillation screen that would have 600 TV lines per inch resolution and neutron conversion efficiencies of 20%. Zenith therefore requested that the requirements of this paragraph be construed as a design goal.

3.2.11 System Equipment. The following comprises the equipment make-up of the system as offered and alternates. Documentation, drawings and a study program were to be included in each program.

I. Proposed system.

- Item 1. 9.4" X 12.6" neutron converter screen.
- Item 2. Lens system.
- Item 3. Modified Westinghouse Image Intensifier/SEC Vidicon camera, containing a WX-30677 and WL-30691 tube combination.
- Item 4. GFE scan/playback subsystem, NASA/MSFC, Contract NAS8-11942.
- Item 5. Contrast enhancement system to be developed and fabricated by Zenith.
- Item 6. GFE Monitor, Conrac Model CQC-17.
- Item 7. Miscellaneous racks and frames, controls and cables.

II. First alternate system.

Same as proposed system, except that the SEC vidicon is a Class 1 Type WL-31189 and the image intensifier tube is a WX3677.

III. Second alternate system.

Same as proposed system except that Item 4 is changed to a video disc recorder and signal processing circuits.

IV. Third alternate system.

A combination of the first and second alternates.

3.3 Design Development

3.3.1 Literature Search. Upon contract award, Zenith initiated a literature search on neutron radiography techniques to ensure maximum utilization of existing knowledge. The prime source of

information appeared to be Berger and Curtiss, but a complete bibliography of all material examined is included in Section 6 of this report.

3.3.2 SEC Vidicon Camera System. Shortly after contract award, Zenith purchased a Westinghouse image intensifier/SEC vidicon camera. The camera was bought to avoid an impending price increase, and since there were indications that the standard Westinghouse WX 30677 Class A image intensifier would be too noisy for extended (more than a few seconds) integration, the camera was delivered without SEC vidicon or image intensifier. NASA was to provide an improved SEC vidicon tube from among those under evaluation, and available image intensifiers were examined.

When all physical components of the camera system were known, design of the mounting system proceeded, together with a new design of the NASA-supplied vidicon and lens mounts. Following acceptance testing of the Westinghouse camera, the unit was modified to accept the combination image intensifier/SEC vidicon. These modifications included machining of the lens-holding bulkhead, purchase of a tube-holding bulkhead, modification of the G4 wiring, changing the SEC vidicon central flange structure insulation (because of the G4 changes) and potting the vidicon central structure to prevent lead flexing. Following tube installation, tests were performed and the camera provided fair results: a standard 525-line scan with 350 lines of horizontal resolution and 6 to 7 grey shades. However, severe non-linearities were present and oscillations appeared in the video chain.

Further effort was expended to eliminate these problems, while maintaining awareness that the NASA-supplied SEC vidicon was a reject tube and performance in excess of 450 lines of horizontal resolution were not to be expected.

Further effort included some minor repairs and an increase in bandwidth from 4 to 6.5 MHz. This, together with additional data obtained from Westinghouse on optimum target and G5 voltages, initially resulted in 550 lines of resolution with a static test chart and photocathode light levels of 1.25×10^{-3} foot-candles and 100% contrast. The ion spot in the SEC vidicon (the cause for its rejection) appeared to degrade low contrast images to a certain extent, making tests of the single lens system inconclusive. It should be noted that these results were also inconclusive because of the difficulty in close inspection of the TV raster in the storage mode; low contrast information is not readily evaluated in bursts of one frame every 15 seconds such as are obtained in the storage mode.

Tests were run soon after this using the SEC vidicon camera in conjunction with two types of radiation detectors using X-ray and gamma radiation. The first was a 0.003" P20 phosphor excited by photons from an 0.5 mm focal spot X-ray source located 36" from the SEC vidicon faceplate. At high radiation levels, resolutions of up to 60 lp/in were obtained. A second test involved an 0.06" cesium iodide crystal, which yielded, at levels of excitation less than 100 mr/sec, resolutions greater than 20 lp/in. The 60-mil thickness of the crystal precluded any higher resolutions.

The second set of tests using gamma radiation from a cobalt 57 source (approximately 165 microcuries) at a distance of 6" from the test specimen showed no radiation indications when used with the P20 phosphor, probably due to the SEC vidicon ion spot masking low contrasts. However, the cesium iodide responded quite well, providing good images of the crystal defects.

A neutron-sensitive image intensifier tube was then coupled to the SEC vidicon through collimating lenses, and resolution measurements were made during X-irradiation. This was done in an attempt to optimize coupling through the system and remove the optics rearrangements necessary when the light-sensitive image intensifier (normally used with the SEC vidicon) is not utilized. X-ray results were encouraging, but attempts to use this set-up with cobalt 57 irradiation indicated that the tube's capability to convert X-ray radiation was inadequate. Therefore, a nuclear medical tube sensitive to gamma radiation was substituted, and images were detected at dosage rates of 2000 gamma photons/cm²/sec (roughly 1 lp/in), which is standard for this type of tube. However, since operation with thermal neutrons yields resolution in excess of 20 mils with 100% contrast, further effort in this area was indicated. It was noted that the SEC vidicon, in the integrating mode, should allow extremely low thermal neutron rates to be used to obtain data.

A second SEC vidicon tube was received from NASA to replace the unit with the ion spot. The second tube appeared free of ion spots, but exhibited lower sensitivity: although 700 lines resolution were claimed by the manufacturer, less than 500 were obtained. Also, less than 10 grey shades were obtained, and it was felt that this tube should be used for neutron tests and

checkout, but not for acceptance.

Sufficient data has been obtained to confirm the desirability of the more expensive neutron image intensifier approach, and Zenith submitted a formal technical discussion and cost summary to NASA for this alternate approach to the conversion of neutron flux to light energy. This approach was substantiated through extensive tests at Argonne National Laboratory, during which useful information of at least 16 lp/in was obtained in the integration mode at flux levels under 5×10^3 N/cm²/sec. Concurrent testing indicated that (1) a grease-coupled, neutron-sensitive conversion screen would provide the necessary resolution, and (2) a double-lens/neutron conversion screen approach was not promising.

Following approval of the neutron image intensifier approach, Zenith commenced modification of existing hardware and drawings to incorporate the new system, and ordered the SEC vidicon camera conversion kit from Westinghouse.

Upon receipt of two new SEC vidicon tubes from NASA and the Westinghouse modification kit, camera system modification was completed. No further problems were encountered except for those associated with the high humidity environment encountered during storage at MSFC.

3.3.3 Scan Converter. Upon receipt and checkout of the GFE scan converter system (Scan/Playback System, ITT, Contract NASA-11942), it was found that a number of defective components were present. Six boards contained faulty components and, most important, the flood gun section of the Iatron tube contained an intermittent filament to cathode leak.

Because of the potential seriousness of this last problem, Zenith obtained permission from NASA to examine other methods of image storage as possible alternatives. A Thorn Electric image retaining panel was purchased and evaluated, and information was obtained from Sony, Ampex, MVR and Data Store on their scan/playback systems. Demonstrations and inspections of equipment from these companies was held at Zenith. A Sony WRS-100 magnetic tape recorder offered at least 10 grey shades, but reduced horizontal resolution. In addition, problems with vertical sync were apparent. MVR's portable disc recorder system yielded nine grey shades with reduced horizontal resolution. On the whole, this system appeared quite promising, requiring only optimization of certain parameters such as bandwidth and electronic triggering to provide a usable system.

Concurrent with the examination of possible alternatives, Zenith attempted a number of methods of repairing the GFE scan conversion unit. Attempts were made to clear the Iatron tube leak by raising the filament voltage past normal limits for a short time, literally "burning" the leak out. Ohmmeter monitors indicated the procedure to have been satisfactory, but when the tube was reinstalled, the same problems existed. The tube being considered unusable, the manufacturer (ITT) was contacted for a replacement, but the high cost and possible future problems with the system made an alternate system even more desirable. A cost-effectiveness comparison of repair costs for the ITT unit versus alternate system costs and advantages was prepared and submitted to NASA. The study offered the following

points for consideration.

1. The ITT GFE unit malfunctions prevented evaluation of the complete system, and incurred extensive delay in the completion of Phase I.
2. Only one Iatron tube replacement was available; others would have to be custom-fabricated by ITT at higher costs.
3. The inherent fragility of the tube is such that replacement tubes could suffer damage in shipment or during the malfunction of control circuits, the latter indicating additional costs to attempt transient protection.
4. If the unit fails again, the system will be out of commission until a replacement tube is procured (or fabricated).
5. The estimated repair cost was \$5,183.50.

In view of the above, Zenith recommended the alternative route of using a video tape or disc recorder instead of the ITT unit.

NASA authorized the purchase of a video disc recorder and Zenith returned the GFE unit. Zenith prepared a set of performance specifications and initiated the purchase of a new system.

The video recorder from Data Disc, Inc. was received and evaluated. Some problems were encountered in the unit, notably in the single- and double-loop servo system operational amplifiers, and inexplicable spikes at the end of a frame following blanking. The former was corrected by amplifier replacement and the latter, with the assistance of a Data Disc engineer, through circuit changes. Interconnections between the video recorder and other units of the system were designed and fabricated.

During preliminary acceptance testing at Argonne National Laboratory, the video recorder failed and was returned to Data

Disc for repair. Following repair, it was shipped directly to MSFC and checkout with the SEC vidicon indicated satisfactory operation.

4. SYSTEM TESTING

This section contains information on test facilities, neutron test sources, and preliminary and final acceptance testing.

4.1 MSFC Neutron Test Facility

The neutron source was located in building 4623 in the MSFC laboratory area. Neutrons were generated by a 2.5 MeV deuteron/beryllium action. Figure 4-1 shows a sketch of the major components in the test facility. On the left is the tank housing the Van de Graaff generator, the left end of which was brought to a positive potential of 2.5 million volts. Deuterium gas was injected into an ionization chamber where it was ionized by an rf field. At the positive potential of 2.5 MeV the deuteron was then repelled into the drift tube where the field is controlled by a series of resistors. Under the influence of this high electrostatic field, the positive deuterium ions were accelerated through the full 2.5-million-volt potential to the right side of the Van de Graaff generator. The length of the Van de Graaff generator was approximately 2 meters and at an accelerating potential of only 2 million volts, the deuteron exited from the right end of the Van de Graaff generator at a velocity of approximately 1.39×10^7 meters per second. At this velocity, the time of transit through the drift tube from the output end of the Van de Graaff to the beryllium target located in the test cage was approximately 430 nanoseconds, assuming no change in the velocity of the deuteron. The reasonably high velocity of this charge particle resulted in some displacement due to the earth's magnetic field; this was corrected by a steering magnet providing a deflection field

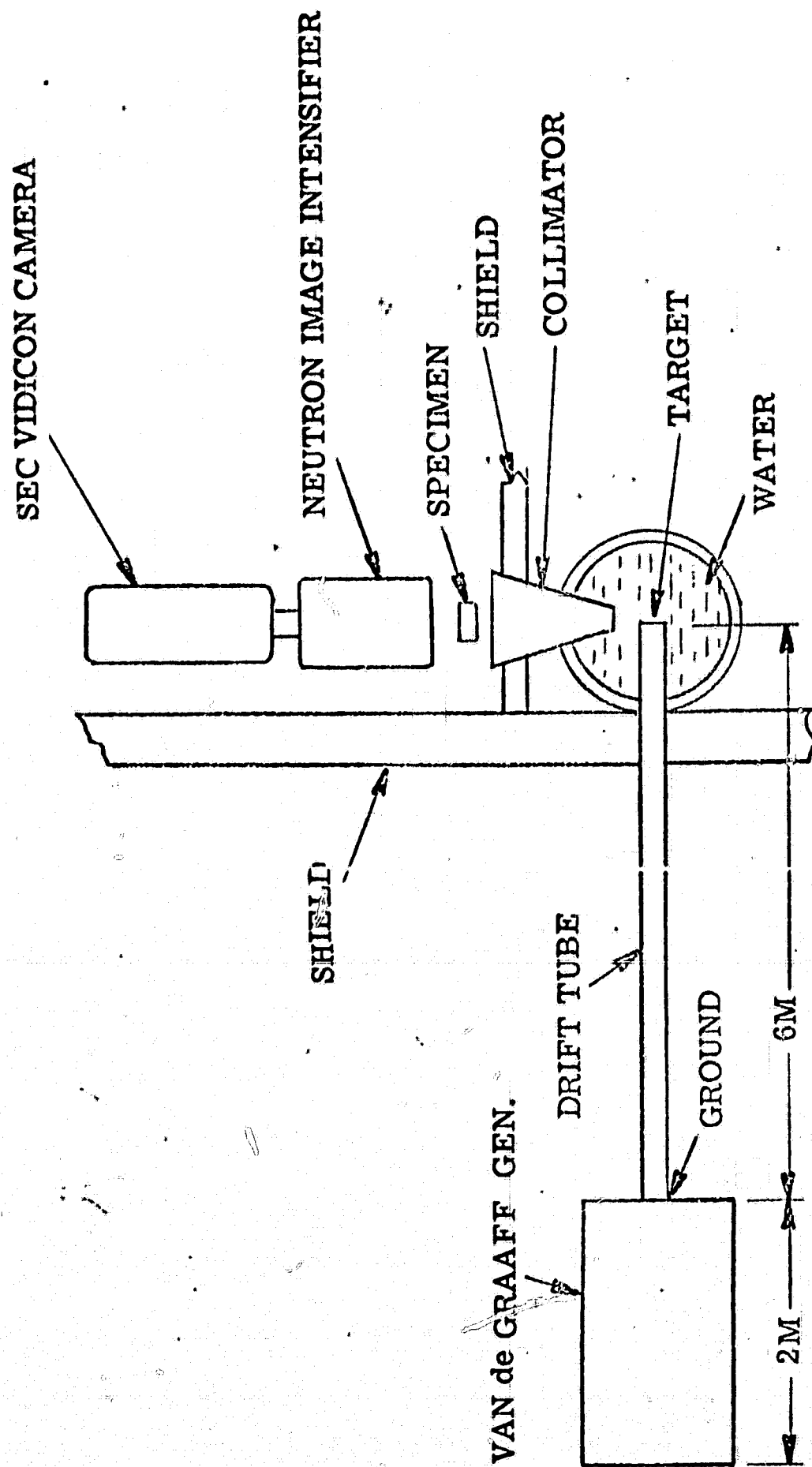


Figure 4-1. Test Facility Components

over a small region of the drift tube.

The energetic deuteron struck a beryllium target located in the center of the moderating water tank. The nuclear reaction is one in which beryllium 9, when struck by a deuteron, produces boron 10. This causes a neutron to be expelled at a reasonably high energy level. Reference 1, pages 14 to 16, discusses this particular reaction and shows the energy spectrum of neutrons that might be expected from the reaction.

Most of the resultant high energy neutrons then entered the water moderating tank and by collision with the hydrogen atoms, proceeded to become thermalized. A horizontal collimator, with between 1-1/2" and 2-1/2" of water, located between the target and the collimator, then picked up the thermalized neutrons. These neutrons, now traveling in reasonably straight lines, proceeded to pass down the collimator to the target and subsequently to the neutron image intensifier. The light output of the neutron image intensifier was then picked up by the SEC vidicon camera.

Note that extensive neutron and radiation shielding in the form of a 10" boric acid-loaded water wall and a 6" lead brick wall shielded the test facility from undesirable gamma and stray neutron radiation. The horizontal collimator was approximately 18" long between input and exit ports, and was approximately 5-3/8" in diameter at the exit port. It was in the form of a conic section with an entrance diameter of approximately 1". The collimator was an aluminum casing with

a cadmium insert. During the testing period, a superior collimator had been constructed and used as a vertical collimator, providing great flexibility in movement and adjustment. Unfortunately, the SEC vidicon system cannot normally be used mounted in a downward-pointing position and insufficient time remained to install the vertical collimator in a horizontal position. The vertical collimator had a superior $1/d$ ratio and in addition, with its larger entrance aperture, provided at least 10 times the flux density of the horizontal collimator. In addition, a lead cadmium sandwich structure was used on the inside which reduced background noise.

4.2 Source Characteristics

The characteristics of most neutron sources are generally defined in terms of flux density in neutrons per centimeter squared per second ($N/cm^2/sec$), flux quantity as a comparison of the faster-than-thermal neutrons versus the number of thermal neutrons, and $1/d$ ratio which indicates the geometry and resolution characteristics that can be expected in the neutron source. In addition, noise or background radiation level is also of importance.

The foil activation technique is generally accepted as an appropriate method of determining the thermal flux density. In this approach, a known quantity of pure material is subjected to the field over a known period of time. The resultant decay radiation count can then be utilized to determine the flux density. Unfortunately, no usable foil counters could be

obtained during the acceptance test period and an alternate technique was utilized to estimate the flux density.

A Victoreen Type BF_3 neutron probe was obtained. This probe was placed inside a cadmium liner which in turn was enclosed by 6" to 12" of paraffin. The cross-sectional area of the probe was approximately 3 square centimeters, and with the thermalizing shielding, it was assured that all thermal neutrons entering the probe on a path which paralleled the axis ionized the BF_3 gas and were counted. A paraffin plug 2" long with a 0.060" cadmium sheet located next to the sensing tube backed by a 0.001" lead paper, were utilized to determine the background count. A 1" paraffin plug with a cadmium liner on the outside was utilized to indicate the fast neutron flux.

Table 4-1 shows the readings taken at the test location in $\text{N/cm}^2/\text{sec}$. A plot of this data is shown in Figure 4-2. It is interesting to note what appears to be a change in slope someplace around 2 million volts. This may be due to changes in the location where the beam strikes the target. Tests have indicated that the neutron flux is directly proportional to the beam current provided the voltage is maintained constant. The second column does not indicate a cadmium ratio of 40:1, but indicates that the faster neutrons are considerably less than the thermalized neutrons from this collimator. No more than a 1.5 to 1 increase is experienced when the thickness of paraffin is reduced from 3" down to 1" with the cadmium shield on the outside. Thus, no large loss in thermalized neutrons

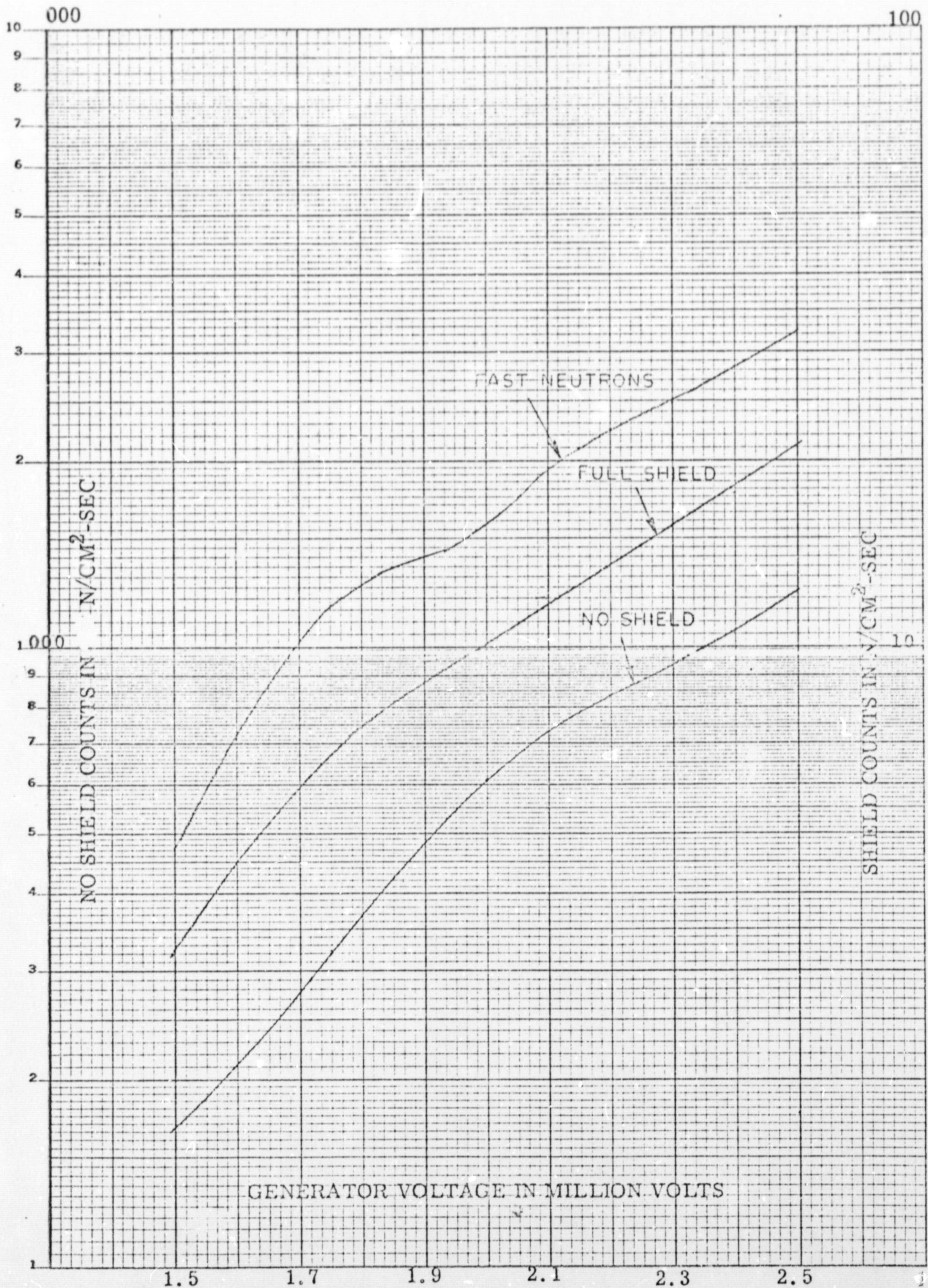


Figure 4-2. Test Location Readings

occurs in the paraffin itself. However, the distribution of the thermalized neutrons with respect to the direction of entry as compared to the final area of exit may be reduced. If one assumes a uniform distribution of thermalized neutrons of a solid sphere whose radius is approximately 1.0", the surface area of the sensor in this simplified geometric model suggests that at least 20 times as many higher than thermal energy neutrons exist as are indicated in Table 4-1. Although neutrons with energy levels above the thermal levels are not readily detected by the neutron image intensifier, they may well be moderated by the subject being investigated and in turn generate scattering thermal neutrons which tend to reduce resolution and increase background noise.

TABLE 4-1

TEST LOCATION READINGS
(current: 50 μ A)

Accel Voltage Mev	Total Flux	Cadmium Shield on Outside	Cadmium Shield on Inside	
1.5	166	4.7	3.2	
1.75	332	11.7	7.2	
2.0	610	15.6	10	
2.1	720	20	12.2	
2.2	834	22.2	13.4	
2.3	940	24.8	15.6	
2.4	1050	28.3	17.8	
2.5	1220	32.2	20.6	

Another parameter of source quality is the apparent l/d ratio. One technique used to obtain this number is by using a neutron image intensifier/photographic combination with a test pattern and determining the reduction of the observable resolution as the distance between the image intensifier sensing area and the test pattern is varied. Over 40 line pairs per inch resolution can be photographically obtained with an extremely thin cadmium test pattern attached directly to the face of the image intensifier tube. The distance from the face of protective dome of this tube to the photocathode of the image intensifier tube is approximately 0.2". When the test pattern to photocathode distance is increased to approximately 1.5", the best resolution can be observed on a photographic positive visually is about 16 line pairs per inch. This is a bar of 0.030" and a space of 0.030". Using a straight geometric interpretation indicates an l/d ratio of 20. Although not closely measured, the l/d ratio of the vertical collimator appears to be at least twice as good. This is to be expected because of an increase in length, higher flux levels which reduce the effective stray flux, and what appears to be a better shield design.

4.3 Preacceptance Test at Argonne National Laboratories.

System tests were run at Argonne National Laboratories Juggernaut IV reactor prior to shipment to MSFC. It should be noted that the maximum flux availability was approximately 2×10^7 N/cm²/sec with l/d ratios in excess of 100:1. The cadmium ratio was better than 3.6:1.

Preliminary testing of the system with this reactor showed a really good 32 line pair resolution to be seen at television scan rates with a neutron flux of 2×10^7 N/cm²/SEC through the entire system of image intensifier, SEC vidicon, disc recorder and TV monitor. When the disc recorder was removed from the system, the TV readout exceeded 40 line pairs per inch.

When the flux was reduced to 10^5 N/cm²/sec, the image intensifier/SEC camera/disc recorder system was capable of providing a good 32 line per inch resolution at an integration time of 1.6 seconds. It became apparent that as the flux level was lowered, the video voltage output of the SEC vidicon camera started to increase and there was indication of target saturation which precluded long integration periods. A correction was made by increasing the f-stop of the imaging lens from f2.8 to as high as f16. This change then allowed increasing of the integration period at fluxes of 10^5 N/cm²/sec. At the lower flux levels the picture seemed to become grainier and it should be recognized that the resolution degrades more slowly than predicted by the integration period neutron flux product. One problem that became apparent at low flux levels was the serious increase in background noise levels due to the filaments of the SEC vidicon tube. It appears that a special procedure in which the filaments are turned off during the integration period as required for periods over 15-second integrations if a reasonable contrast is to be maintained. Successful radiographs were made in the integrating mode at levels of approximately 100 to 500 N/cm²/sec with resolutions in excess

of 16 line pairs per ^{inch} minute. At these levels it was necessary to insert a neutral density 1.0 Wratten number 96 filter into the light path in order to prevent saturation of the SEC tube.

With respect to the high resolution configuration, a 0.010" thick $^6\text{LiF/Cd}$ mixture was placed on an aluminum disc. An Argonne neutron test strip containing five 0.010" holes in a row was placed approximately 3/8" above the back of the disc. This combination was then tested at TV rates and separation could be distinguished with neutron fluxes to $2 \times 10^7 \text{ N/cm}^2/\text{sec}$.

A neutron test wedge block was tested and at least 5 grey shades could be determined through the total system at TV rates and $2 \times 10^7 \text{ N/cm}^2/\text{sec}$.

4.4 Van de Graaff Acceptance Test

As indicated in paragraph 4.1 the flux strength from the present Van de Graaff generator configuration was approximately two orders of magnitude lower than anticipated. In addition, the l/d ratio was also somewhat less than anticipated. With SEC vidicon lens f-stops of 1.4 to 2.0, the characteristic bouncing "ping-pong ball" effect such as exists with all low quantity quantum systems was noticeable. This condition occurring at TV readout rates, only large items such as 1" cadmium discs could be observed. In all cases integration modes were required to pick up usable neutron radiographs.

The SEC vidicon camera together with the disc recorder were optimized with optical test patterns and the final infinity focus on the imaging lens was made visually on water towers approximately three miles away. The best focus of the neutron

image intensifier required a dynamic operating system in which both the SEC camera and recorder would be required. A cadmium wedge pattern was used and integration single field readouts were made at a rate of approximately once every 10 seconds. Thus, several changes were allowed before an adjustment in either the E1 or E2 focusing voltage of the image intensifier was made. Under these conditions the image intensifier resolution was optimized. This process was confirmed by directly photographing the screen of the neutron image intensifier. Resolutions of 40 line pairs per inch were noted and there appeared to be some streaking at 50 line pairs per inch. It should be stressed that this test pattern was a very thin pattern, and attached to the neutron image intensifier tube. These tests were performed with the horizontal collimator at maximum power of 2.5 mv and 100 μ A of beam current. An f-stop of f/11 was used with 5.0 minutes of integration time. Polaroid type 52 film was utilized to obtain this image. It does not appear that increased integration times at higher f-stops improve the neutron resolution of the image.

A series of photographs of the monitor were taken when the test pattern was mounted on the dome of the image intensifier tube. The imaging lens on the SEC camera was at f/16 and the recording was made on a field-by-field basis with approximately 45 seconds integration time. A good 32 mesh was detected under these conditions and some streaking was noted at 40 mesh with integration times of 45 seconds. One problem was the still large noise level due to the neutron quantum effects, over and above the television camera initiated noise.

Longer integration times, which would have required larger f-stops and possibly insertion of neutral density filters in the light path would be required to obtain neutron radiographs with less quantum noise. Integration times at this flux level might reach two or three minutes per field (see Figure 4-3). Additional tests were made with a test wedge coupled with a test bar. Holes of 0.015" diameter could be observed but streaks between 15-mil holes could not. Again, the l/d ratio coupled with the short integrating time contributed to the reduction of resolution in the system.

The thin disc containing ^6LiF and CdS was attached directly to the SEC vidicon tube and a test strip was utilized. When this strip was examined, 50-mil holes could be observed, but the distance between the strip and the disc, together with the l/d ratio and low fluxes, precluded high resolution radiographs. The quality of this radiograph was far poorer than those obtained in the earlier test at Argonne and was probably due to the change in sources. No neutron radiographs could be made at this facility in less than 15 seconds integration period, and all required a special test cycle in which the filaments of the SEC vidicon tube was turned off.

Several test valve switches were used as specimens. Photographs of the TV monitor are shown in Figures 4-4 and Figure 4-5. Since the bulk of the specimens caused some of the internal parts to be as far as 3" from the faceplate of the image intensifier tube, resolution was badly reduced, probably not exceeding 12 line pairs per inch. However, the basic hydrogenous and cadmium parts could be observed.

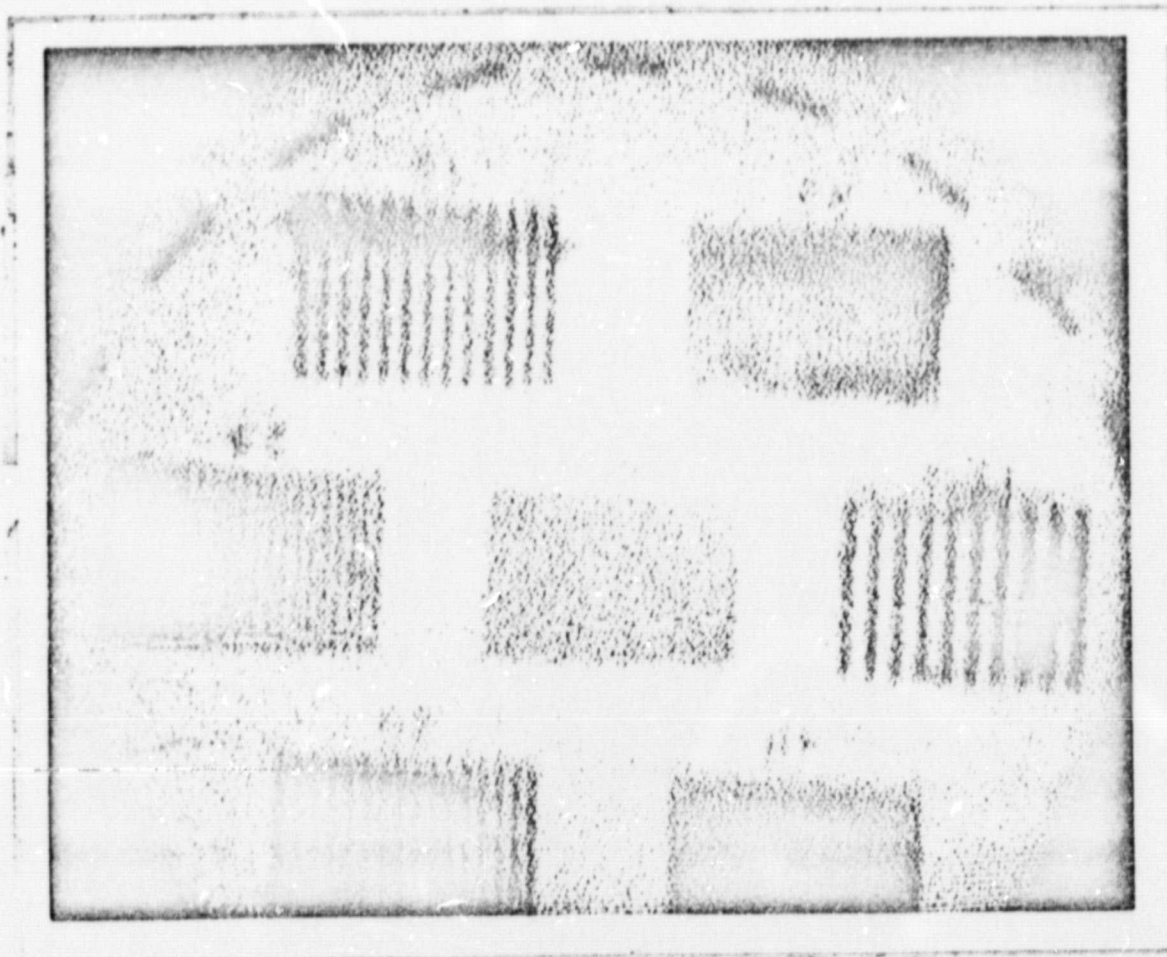


FIGURE 4-3



FIGURE 4-4



FIGURE 4-5

4.5 Test Conclusions

The neutron tests made with the Van de Graaff generator indicated that the resolution of over 30 line pairs per inch can now be made directly from the image intensifier/SEC vidicon system. The photographic approach used in the neutron image intensifier tube indicated that long-term integrations of five minutes at maximum flux were capable of producing 40 and perhaps even 50 line pairs per inch directly from the tube with the source and very thin targets. The television camera and disc recorder using light and in the storage mode produced over 450 lines TV horizontal resolution. Thus it appears that the TV system could display 40 line pairs per inch. The neutron quantum noise may be causing the problem. It should be stressed that much more experimentation must be done with the system and the Van de Graaff generator before an optimum set of operating conditions is determined.

The second (vertical) collimator, which has at least 10 times the flux density and perhaps twice the l/d ratio, undoubtedly would provide far better neutron radiographs and should be incorporated in the present system. The high resolution system in which an aluminum-coated disc is used requires that the test specimen be very close to the disc, and in general, one can expect high resolution separations to be observable only in rather thin objects which can be closely attached to the viewing screen. Obtaining quality grey shade rendition may be a problem when hydrogenous materials are used because of the rather large scattering coefficient of hydrogen as compared to rather low absorption coefficient. The scattering

coefficient should produce a high level scatter flux which would have the advantage of spreading the apparent specimen or target size. There would be a disadvantage in reducing the clarity of small separations between objects. The scattering effect would also tend to produce an increase in the background noise of the neutron radiograph.

With regard to the image-enhancing equipment, although it did display over 100 different shades of grey, an important factor is the quality of the signal being analyzed. In some cases a noisy signal gives no more information when processed by the contrast enhancer. Thus it is important that the signal have relatively low noise levels. The quantum effects on the signal due to the limited amount of neutrons indicates that if more information is required, longer integration times must be used. The observed necessity to reduce the light level from the neutron image intensifier to the SEC vidicon raises some questions as to what causes the non-reciprocity function. Previous experiments with the image intensifier have shown that it is a linear device well over 10^8 N/cm²/sec. The electronics of the SEC vidicon camera are somewhat controlled by an automatic light control which changes the voltage over the imaging section of the SEC vidicon. It appears that it is this circuitry that may be somewhat responsible for the change in reciprocity of the system. The SEC vidicon camera has a destructive readout, and therefore, the first field comes out at a reasonably strong strength while the second field is almost completely obliterated since the first readout beam

removed all the information. In actual practice it is quite suitable and preferable to put the camera on sequential field readout in which only one field is read out after each integration period. Although this approach takes twice as long to turn out a full frame, it produces a static picture with full resolution and grey shade renditions. Frames obtained in this manner are superior to the other condition of one full frame readout each time.

One modification that can lead to immediate improvement is in the installation of the vertical collimator in a horizontal position. The increase in flux by at least one decade will allow a reduction in the integration time by at least 10. The long period integration cycle requires a rather complex sequence of switch operations, with at least four switches to be manipulated. It appears that an automatic filament on/off sequencer should be provided if integration time is in excess of 15 seconds will be commonly required in the system use. A second alternative is to use a photocathode in the SEC vidicon which is insensitive to the filament radiation.

Much work has to be done in the actual utilization of this equipment. One advantage of this equipment is speed, being several thousand times faster than conventional film screen combinations and at least 5 to 20 times faster than film coupled with the image intensifier tube. This advantage is quite badly compromised by the present procedure required to change a specimen position. The Van de Graaff generator must be cut off, then the operator must pass through several interlocked doors, change the specimen position or configuration, relock the doors, and then re-start the Van de Graaff generator. The minimum

time of this cycle is approximately five minutes, and it is conceivable that under adverse conditions, it might take 15 or more minutes. Thus, to obtain full utilization of this equipment especially when increased flux is made available, it is important to supply remote manipulating equipment.

As in X-ray radiography, a whole area of radiographic technique development will be required. Thus, a Bucky-like neutron screen and a special mask-off region may provide invaluable aid in improving both contrast and resolution of the neutron radiograph.

The contrast enhancement equipment works with reasonably quiet signals and has provided some aid in evaluation of the actual television neutron radiographs. However, it must be stressed that the contrast enhancement picture can show nothing that is not already present in the signal and tends to accentuate noise in the picture. Thus, the present design is an aid to rapid evaluation of some type of picture detail rather than being able to give any really new information on the picture content. To become really effective, the quantum noise effects must be reduced.

5. RECOMMENDATIONS

The present neutron radiographic viewing system is now operational; however, the actual application of this equipment to nondestructive testing still requires a considerable amount of testing and evaluation. On this basis, the following suggestions are made:

1. Improvement in the collimation and flux densities of the system. It appears that fluxes of at least 10^6 N/cm²/sec with 1/d ratios of 50 to 100 are theoretically possible with this particular Van de Graaff system. This involves some experimental work with the collimator, together with the physical location of the collimator, moderator and target.
2. A more exact or conventional determination of the quality and quantity of the neutron flux available. This will require the use of foil activation and film techniques. A complete mapping of the flux field, including the areas immediately in the vicinity of the beam is important.
3. Studies using practical specimens to reduce the effect of scatter radiation from the specimen itself. These would include special field limiting equipment, Bucky screen types of arrangements, etc., which have been in reasonably common use in X-ray radiography and may require some modification and techniques for neutron radiography. This requires a good bit of experimentation by personnel familiar with X-ray radiography techniques.

4. An investigation of the apparent failure of the reciprocity effect of the time-density product. It is suggested that the effects of the SEC vidicon camera automatic light control be studied closely, and, in the event that this is the main offender, that the SEC vidicon image section be operated at lower voltages. Normally a lowering of the voltage leads to a lowering of the noise signals.
5. Since it appears that very long integration times will be required in the system, it is suggested that a special circuit be devised which will allow an operator to enter a specific time, such as three minutes or more, thereby taking care of the integration automatically.
6. The installation of remote specimen handling and manipulating equipment so that the time advantage gained by this viewing system can be fully utilized and not compromised by the long periods required to having humans enter and manipulate the component. This will have a further advantage of high flux levels, in that it is quite possible that the component can be shown at television rates. Again, it is stressed that automatic remote component-manipulation of the equipment is a must for the system.
7. The development of a whole series of tables in which the radiographer can determine integration times versus flux densities, specimen thickness, material, etc.,

so that neutron radiography reaches the point of being as routine a piece of equipment to utilize as is normal X-ray radiographic equipment. It would also be interesting to see what the change in the spectrum due to increased voltages does to a wide range of neutron radiographs. As in X-ray radiography, it may be found that the change in the energy of the prime radiation has some effect on the final resultant neutron flux.

6. BIBLIOGRAPHY

1. Berger, H.: Neutron Radiography, Elsevier Publ. Co., 1965.
2. Curtiss, L.F.: Neutron Physics, Boston Technical Publishers, Inc., 1965
3. Barton, J.P. and Klozar, M.F.: "Californium-252 as a Neutron Radiographic Source", unpublished report, 1969.
4. Berger, H.: "Characteristics of a Thermal Neutron Television Image System," Materials Evaluation, September 1966.
5. Berger H., Niklas, W.F., Schmidt, A.: "An Operational Thermal Neutron Image Intensifier," Journal of Applied Physics, Vol. 36, June 1965.
6. Saldi, I.T., et al: "Light Sensitive Imaging Tubes," Electronic Industries, May 1966.
7. Derick, B.N. "Fiber Optics," Machine Design, October 1970.