APPLICATION FOR RENEWAL

1969

AEC LICENSE #12-8271-1

RADIOGRAPHY WITH Co 60

GENERAL STEEL INDUSTRIES, INC.

A/30

GENERAL STEEL INDUSTRIES, INC.

DIRECTORS

Mr. Joseph H. Bascom, Pres.
Broderick & Bascom Rope Company
10440 Trenton Avenue
St. Louis, Missouri 63132

Mr. Stuart W. Cragin
Chairman Credit Committee
Morgan Guaranty Trust Company
23 Wall Street
New York, New York 10015

Mr. Duncan C. Dobson, Pres.
Ludlow-Saylor Wire Cloth Company
4333 West Clayton Avenue
St. Louis, Missouri 63101

Mr. James K. Ebbert, Vice Pres.
Mellon National Bank & Truct Co.
Mellon Square
Pittsburgh, Pennsylvania 15203

Mr. Van Horn Ely, Jr.
430 Continental American Building
Wilmington, Delaware

Mr. W. Ashley Gray, Jr.
President
General Steel Industries, Inc.
One Memorial Drive
St. Louis, Missouri 63102

Mr. Edwin S. Jones, Exec. Vice Pres.
First National Bank in St. Louis
305 North Broadway
St. Louis, Missouri 63102

Mr. Preston D. Law, Chairman
Flex-O-Lite Division
P. O. Box 4266
St. Louis, Missouri 63123

Mr. Edwin B. Meissner, Jr. Senior Vice Pres
One Memorial Drive
St. Louis, Missouri 63102

Mr. Henry B. Pflager
Orr, Pflager & Andreas
Boatmen's Bank Building
314 North Broadway
St. Louis, Missouri 63102

Mr. Nicholas P. Veeder
Chairman of the Board & President
Granite City Steel Company
20th & State Streets
Granite City, Illinois 62040

Mr. Charles P. Whitehead
Chairman of the Finance Committee
General Steel Industries, Inc.
314 N. Broadway
St. Louis, Missouri 63102

GENERAL STEEL INDUSTRIES, INC.

OFFICERS

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George K. Hoblitzelle
Vice President & Secretary
One Memorial Drive
St. Louis, Missouri 63102

GENERAL STEEL INDUSTRIES, INC.

CASTINGS DIVISION

1417 State Street
Granite City, Illinois 62040
618 · GL 2-2120

February 17, 1969

Mr. James Milaro
Senior Reviewer
Division of Licensing and Regulation
United States Atomic Energy Commission
Washington, D. C. 20545

Dear Mr. Milaro:

Enclosed is our application for renewal of the United States Atomic Energy Commission Byproduct Material License #12-8271-1. The only physical changes made to our facilities are in the location of the crankout device for the 80 curie cobalt 60 source and some additional safety devices for the same source. These are described in Section 6.

The application has also been updated to reflect changes in corporate and departmental personnel.

Your review of this application will be appreciated.

Sincerely,

H B Norris

H. B. Norris
Manager of Quality Control

HBN:lw

Enc.

614 9om

Form AEC-313R
(9-62)

UNITED STATES ATOMIC ENERGY COMMISSION

APPLICATION FOR BYPRODUCT MATERIAL LICENSE— USE OF SEALED SOURCES IN RADIOGRAPHY

Form approved.
Budget Bureau No. 38-R137

SEE ATTACHED FORM AEC-313R INSTRUCTIONS—USE SUPPLEMENTAL SHEET WHERE NECESSARY
BE SURE ALL ITEMS ARE COMPLETED AND THAT ALL NECESSARY ATTACHMENTS ARE FURNISHED. IF ANY PORTION OF THE APPLICATION IS NOT APPLICABLE SPECIFICALLY SO STATE. DEFICIENT OR INCOMPLETE APPLICATIONS MAY BE RETURNED WITHOUT CONSIDERATION.

1(a) NAME AND ADDRESS OF APPLICANT

General Steel Industries, Inc.
1417 State Street
Granite City, Illinois 62040

2. PREVIOUS LICENSE NUMBER(S) *(Indicate if application is for renewal or amendment of an existing byproduct material license.)*

Renewal of License #12-8271-1

1(b) APPLICANT IS: An individual ☐ A partnership ☐ A Corporation ☒ An Unincorporated Association ☐ Other ☐ If applicant is other than an individual, the applicable section on the reverse side must be completed.

3. LOCATION(S) WHERE SEALED SOURCES WILL BE USED AND/OR STORED. *(If use will be made in states other than named in 1(a), they should be listed here.)*

General Steel Industries, Inc.
1417 State Street
Granite City, Illinois 62040

4. SEALED SOURCES TO BE USED IN RADIOGRAPHY
Budd Assembly No. 300-041706 (B)
Radionics Inc. P60-100-2

BYPRODUCT MATERIAL (Element and Mass No.)	SOURCE MODEL NUMBER	NAME OF MANUFACTURER	MAXIMUM ACTIVITY PER SOURCE	NUMBER OF SOURCES
A. Co60	A. C-374	A. Nuclear Consultants Corp.	A. 280 mc	A. one
B. Co60	B. C-375	B. " "	B. 260 mc calibrated 7-22-62	B. one
C. Co60	C. P60-100	C. Radionics Inc.	C. 80 curie	C. one

5. RADIOGRAPHIC EXPOSURE DEVICES AND/OR STORAGE CONTAINERS TO BE USED WITH SOURCES LISTED ABOVE

MODEL NUMBER	NAME OF MANUFACTURER *(If custom made, attach complete design specification.)*
A. Unitron 110A Serial #1116	A. Budd Company Instruments Division
B. Unitron 110A Serial #1117	B. Budd Company Instruments Division
C. 1 Model P60-100-2	C. Radionics Inc.

6. THE FOLLOWING INFORMATION IS ATTACHED AS A PART OF THIS APPLICATION: *(Check appropriate blocks and attach information called for in the instructions with this form.)*

	Not Applicable	Attached	Previously Submitted
(a) Description of radiographic facilities (Instruction 6–a)	☐	☒	☐ on Jan. 15, 1968 (DATE)
(b) Description of radiation detection instruments to be used (Instruction 6–b)	☐	☒	☐ on Jan. 15, 1968 (DATE)
(c) Instrument calibration procedures (Instruction 6–c)	☐	☒	☐ on Jan. 15, 1968 (DATE)
(d) Personnel monitoring equipment (Instruction 6–d)	☐	☒	☐ on Jan. 15, 1968 (DATE)
(e) Operating and emergency procedures (Instruction 6–e)	☐	☒	☐ on Jan. 15, 1968 (DATE)
(f) Training program (Instruction 6–f)	☐	☒	☐ on Jan. 15, 1968 (DATE)
(g) Internal inspection system or other management control (Instruction 6–g)	☐	☒	☐ on Jan. 15, 1968 (DATE)
(h) Overall organizational structure (Instruction 6–h)	☐	☒	☐ on Jan. 15, 1968 (DATE)
(i) Leak testing procedures (Instruction 6–i)	☐	☒	☐ on Jan. 15, 1968 (DATE)

CERTIFICATE (This item must be completed by applicant)

7. THE APPLICANT AND ANY OFFICIAL EXECUTING THIS CERTIFICATE ON BEHALF OF THE APPLICANT NAMED IN ITEM 1, CERTIFY THAT THIS APPLICATION IS PREPARED IN CONFORMITY WITH TITLE 10, CODE OF FEDERAL REGULATIONS, PART 30, AND THAT ALL INFORMATION CONTAINED HEREIN, INCLUDING ANY SUPPLEMENTS ATTACHED HERETO, IS TRUE AND CORRECT TO THE BEST OF OUR KNOWLEDGE AND BELIEF.

General Steel Industries, Inc.
Applicant Named in Item 1

By: T. Ditchfield

DATE February 6, 1969

Vice President - Manufacturing
Title of Certifying Official

WARNING.—18 U.S.C., Section 1001, Act of June 25, 1948; 62 Stat. 749; makes it a criminal offense to make a willfully false statement or representation to any department or agency of the United States as to any matter within its jurisdiction.

06452

FORM AEC-313R (9-62)

LEGAL STRUCTURE OF APPLICANT

If applicant is a corporation, complete Items 8 through 11; if applicant is a partnership, complete Items 12 through 14; if applicant is an unincorporated association or a legal entity other than a partnership or corporation, complete Items 15 and 16. Attach separate sheets where space provided proves inadequate.

CORPORATION

8. STOCK OF APPLICANT CORPORATION

NO. OF SHARES AUTHORIZED	NO. OF SHARES ISSUED	NO. OF SHARES SUBSCRIBED	TOTAL NUMBER OF: (a) Stockholders	TOTAL NUMBER OF: (b) Subscribers
6,000,000	2,266,148		7850	

9. Is applicant corporation directly or indirectly controlled by another corporation or other legal entity? YES ☐ NO ☒
If answer is "YES" give name and address of other corporation or other legal entity and describe how such control exists and the extent thereof.

10. (a) Identify by name and address any individual, corporation, or other legal entity (1) owning 10 percent or more of the stock of applicant corporation issued and outstanding or (2) subscribing to 10 percent or more of the authorized but unissued stock of the corporation.
(b) Identify by name and address all officers and directors of the corporation.

(a) None
(b) See Attached

11. Identify the State, District, Territory, or possession under the laws of which the applicant is incorporated.

PARTNERSHIP

12. Name and address of each individual or legal entity owning a partnership interest in the applicant.

13. State the percent of ownership of the applicant partnership held by each of the individuals or legal entities listed in Item 12.

14. Identify the State, District, Territory, or possession under the laws of which the applicant partnership is organized.

OTHER

15. Describe the nature of the applicant and identify the State, District, Territory, or possession under the laws of which it is organized.

16. State the total number of members or persons holding an ownership in the applicant, identify each by name and address, and indicate the ownership interest thereof.

* U.S. GOVERNMENT PRINTING OFFICE : 1962 OF—659351

January 28, 1966

Memorandum to Mr. T. Ditchfield

To conform with A.E.C. regulations for the use of the two Co 60 isotopes in our plant, the following must be carried out at all times:

1. Before anyone is allowed on the roof of #6 building over the #6 building x-ray cage, Mr. H. B. Norris, Radiation Safety Officer, must be notified and his permission obtained.

2. Before anyone is allowed to work on the #6 building overhead cranes, when and if this work is done over the #6 building x-ray cage, Mr. Norris again must be notified and his permission granted.

These instructions were originally sent to Messrs. Roddy and McMillin. Due to the changes in personnel and the continued use of Co 60, I thought it wise to reissue these instructions.

This letter will become a part of our A.E.C. licensing application, replacing the original addressed to Mr. Barclay, dated January 29, 1963, and the first revision addressed to Mr. McMillin, dated January 3, 1964, and the second revision addressed to Mr. Ditchfield, dated November 27, 1964.

H. B. Norris
Radiation Safety Officer

HBN:ten

cc: WED LFB(6) MWL ROC

C8458

6. (a) DESCRIPTION OF RADIOGRAPHIC FACILITIES

January 25, 1963

Mr. William E. Davis
Plant Metallurgist
General Steel Industries
1417 State Street
Granite City, Illinois

Dear Mr. Davis:

Enclosed you will find a cross sectional drawing of your foundry building #6 in the area of your radiographic room.

As you will recall, last Saturday (January 19, 1963) during my visit to your plant I made a complete radiation survey of the area immediately above the radiographic room to determine, by measurement, the actual radiation fields present when your Co-60 radiographic sources are in use.

I had previously made calculations of these fields for you, however, during your last A.E.C. inspection the question was raised as to the actual measurements of these fields. Since it was a bad, snowy day I declined the invitation to crawl around on top of the roof to make actual measurements! I did, however, personally climb into the crane cab and on top of this cab where there is a catwalk which spans the complete building immediately above the radiographic room.

These measurements were made with an NRD Model CS-40 ionization type survey meter. This meter had been calibrated in our laboratories using a Bureau of Standards calibrated Co-60 standard.

Two measurements were made - one with both sources placed inside of large casting as you would normally use them and the second set of readings were made with both sources laying unshielded on the floor of the radiographic room.

Table one shows the measurements actually taken. From this it can be seen that the crane operator is quite safe even when both sources are completely exposed. The field immediately above the sources on the catwalk reaches a maximum of 7 mr./hr. when both sources are completely exposed. This does not present a problem since you already have a company policy established that no-one is allowed on the catwalk without first checking with your office. No-one should, of course, be allowed on this catwalk when the sources are in use.

The other question posed by the inspector was the possible radiation fields on the roof. As I stated earlier, I did not physically go to the roof for measurements, however, I'm sure we have ample data to calculate the fields in the positions indicated on the roof. I have selected all points where it would be possible for maintenance men to be required to work. Table II gives the calculated values for these various positions.

As can be seen from this table, the highest field is that in the ridge area immediately above the exposed sources at position I. This represents a field of 0.85 mr./hr - well below the 2 mr./hr for unrestricted areas and would mean a person would have to remain at this position about 120 hours per week in order to exceed the 100 mr. per week limit. A most unlikely situation.

I would, however, recommend you extend your company policy of requiring all maintenance men to clear through your office before going onto the catwalk of the crane to include going onto the roof also. In this manner you can be certain no workmen will be in these areas when the sources are exposed.

I further recommend you make this report a part of your permanent records and submit a copy to both the state and federal A.E.C. inspection agencies in answer to any questions they may have concerning the radiation fields and control of areas above your radiographic facilities.

Should you have any further questions, please call on me at your convenience.

Sincerely,

NUCLEAR CONSULTANTS CORPORATION

W. R. Konneker, Ph.D.
Certified Health Physicist

WRK:im
cc:WRK

enclosures

TABLE I

		sources in casting	sources on floor
A.	Seat of the crane operator	0.5 mr./hr.	1 mr./hr.
B.	Catwalk on top of crane	1 mr./hr.	1 1/2 mr./hr.
C.	Catwalk immediately above wall	1 mr./hr.	3 mr./hr.
D.	Catwalk immediately above sources	3 1/2 mr./hr.	7 mr./hr.
E.	Catwalk about half-way between sources and operator's position	1 1/2 mr./hr.	2 1/2 mr./hr.
F.	Catwalk immediately above operator's position	1 mr./hr.	1 1/2 mr./hr.
G.	Catwalk immediately above end wall of room	0.5 mr./hr.	1 mr./hr.

TABLE II

All based on both sources completely exposed using closest measured point and the inverse square law. No additional shielding assumed.

L. Area between two buildings 68' from sources (use measured field at C for calculation).	0.4 mr./hr.
H. Platform inside building used to work on window controls 60' from sources (used measured field at C for calculation).	0.52 mr./hr.
I. Ridge area on top of roof 52' from sources (used measured field at D for calculation).	0.85 mr./hr.
J. A second platform inside building used to work on window controls 56' from sources (used measured field at E for calculation).	0.45
K. Edge of building 62 feet from sources (used measured field at F for calculation).	0.4 mr./hr.

General Steel Industries in its normal operation produces a wide range of very large steel castings for the military and for industry. Extensive testing, including radiographic inspection is required for most of these castings. To date, we have used quite satisfactorily two 500 mg. radium sources. These have been used with a fish pole technique with little radiation exposure to our personnel. To more easily comply with state regulations and to reduce our cost by purchasing rather than leasing material, we have decided to obtain two 300 mc Cobalt 60 sources from the Budd Company which will be mounted in two of their Unitron Model 110A roll-out cameras. These sources and cameras will be used only in the specially constructed room inside the plant in Granite City. Although the cameras are of the portable type, they will not be used in other parts of the plant nor in the field.

See attached drawing for the radiographic room. This room is 22 feet wide by 60 feet long and the walls are constructed of 24 inches of sand filled concrete block. The room is located inside our foundry and hence does not have a roof. There is no basement nor open area under the room. The walls are approximately 10 feet high with three strands of barbed wire atop the wall to make certain unauthorized personnel do not enter. Red warning lights are installed on each wall and over the doorway. There is only one door into the room which is located on the north wall. This door is posted and always kept locked. Only Mr. Norris and the radiographers working under his supervision have access to the keys. The building superintendent never goes into the room without first contacting Mr. Norris. He does not have keys for the source storage containers. Inside the room, in the northeast corner, is a small viewing room of about six by six feet square. The walls of this room are 20 inches thick made from cement blocks. Between the radiographic area and the control area are several large pieces of armor plate steel as shields. These armor plates are 4 inches thick and measure six by six feet square.

All area immediately surrounding this room are either storage areas or run ways for the movement of material and castings. Except for the door area, the area for approximately 20 feet adjacent to the north wall is storage and not used as a work area. The area adjacent to the east wall is likewise primarily used for storage and although personnel can approach to within 4 or 5 feet of the wall, there is no working area closer than 15 feet away. The area behind the south wall is pretty much inaccessible to personnel being used to store drums of oil. The west wall faces a run way through which small trucks or tractors move castings, molds and other material. The closest work area is some 15 to 20 feet away.

All castings are placed in this room through the open ceiling by the use of overhead cranes. The large overhead cranes span the whole width of the large building (approximately 100 feet wide). The control cabin is located at the far south side of the large building and some 25 feet in the air. The distance from the wall of the radiographic room to a point directly under the control cabin is approximately 40 feet. Hence, the closest distance from the wall to the cabin is on the order of 50 feet. Since the crane operator is working from a point so far behind the south wall of the room (although some 25 feet up) he is unable to see or place castings closer than 3 or 4 feet from this wall. If there is a single casting, it is placed nearly in the center of the room. If there are two (the maximum handled at any one time) they cannot both be centered of course which results in each being slightly closer to the side walls. Most work is done with the capsule inside the casting with the film placed on the outside. For this reason very small source to film distances (3 to 6 inches) are used and hence the reason for the small sources (300 mc each). This technique, with the source inside the casting results in considerable absorption of the radiation in the casting and hence results in much reduced radiation fields.

The large overhead crane is never operated over the areas where the radiographers' room is located except to place the castings to be radiographed into the room. It can be shown however that the maximum radiation field which could exist at the cabin of this crane is between 2 and 2.5 mr per hour. Since the occupancy factor in this position is virtually zero, we consider this to be an unrestricted area.

The operator of the radiographic units will be some 25 to 35 feet away from the exposed sources and will operate behind 4 inches of armor plate steel.

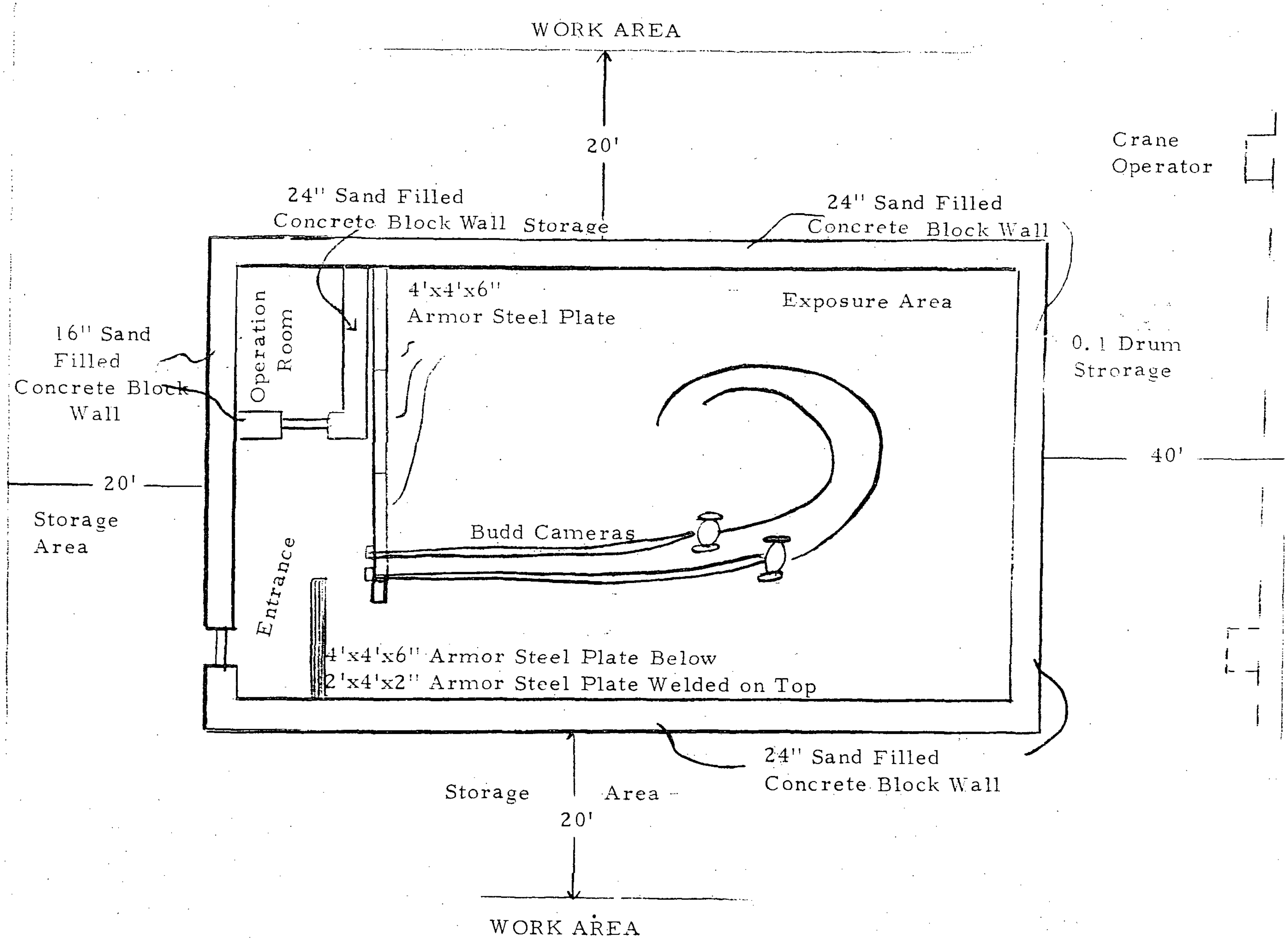
The only door to the room is locked and posted on the outside and is likewise locked from the inside when a radiographer is inside working. Because of the noise level in the plant, it would be possible for unauthorized personnel to enter the room unnoticed even with the operator in the room if he did not lock the door after him. There is a buzzer on the door to signal the operator from the outside.

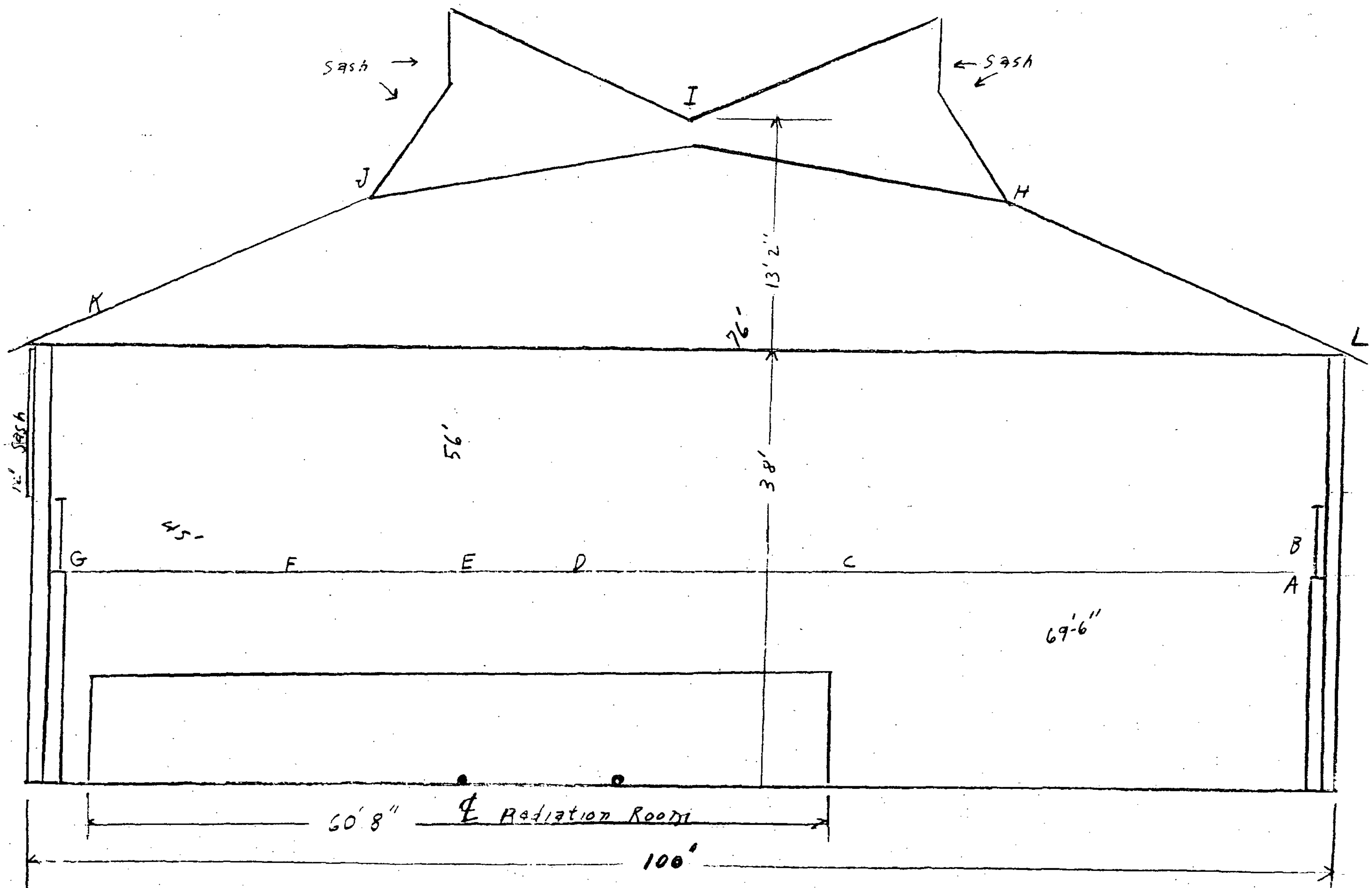
A large red light is mounted on the top of each wall. One is mounted on the north wall immediately above the door. These lights are turned on whenever an operator enters the source room or whenever sources are exposed. The light can easily be seen not only by someone attempting to enter the door, but also by the crane operator and anyone in this whole area of the plant.

Radiation area and radiation storage signs are posted on the entrance doorway. Additional radiation signs are posted within the radiographic enclosure in conformance with A.E.C. regulations.

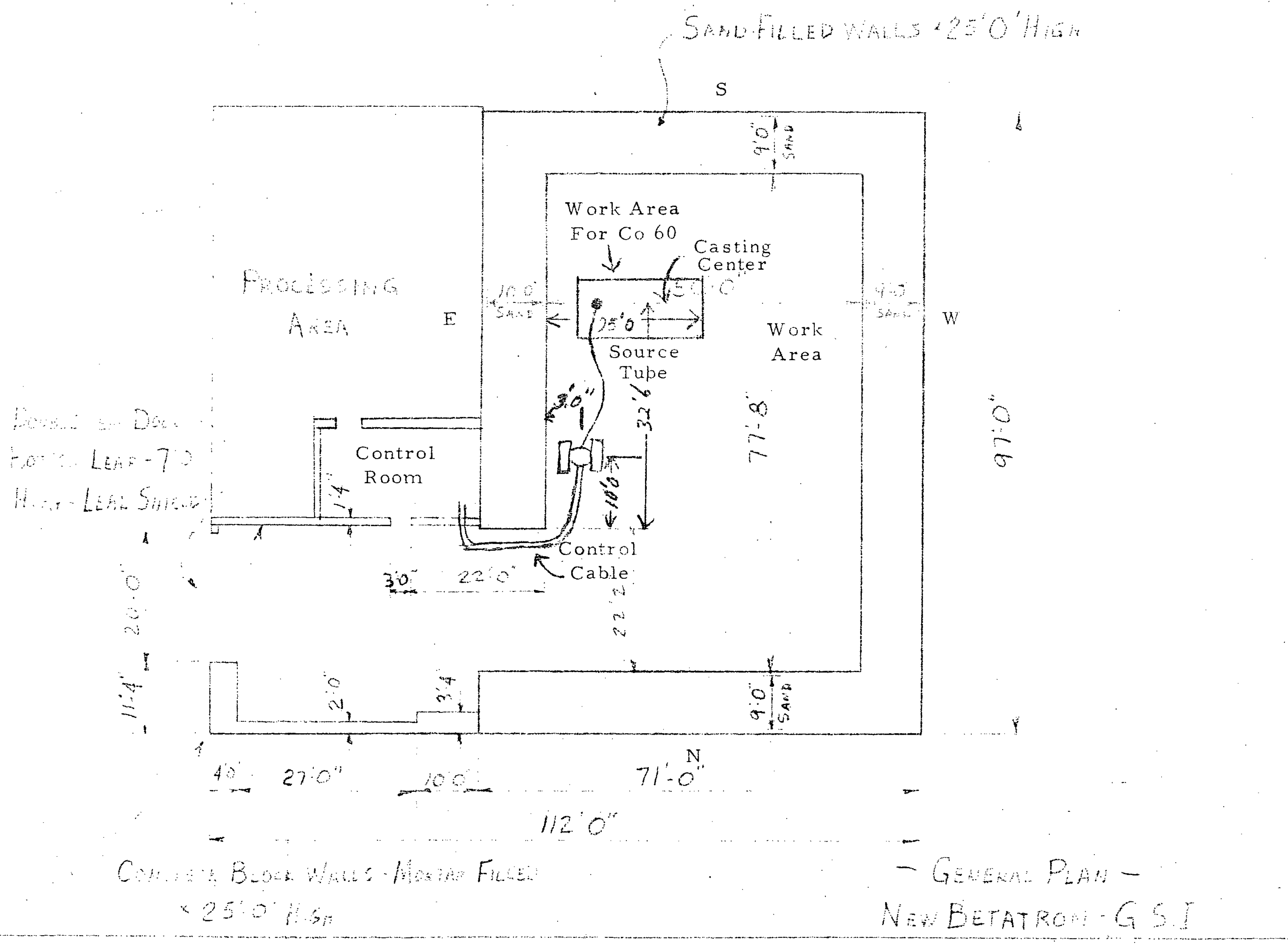
In addition, due to the work load of large industrial castings, General Steel Industries has decided to obtain one 80 curie cobalt 60 source from Radionics Inc., which will be mounted in a radiographic camera model P60-100-2. This source and camera will be used only in the specially constructed Betatron room inside the plant in Granite City. Although the camera is of the portable type, it will not be used in other parts of the plant nor in the field. See attached drawing for the radiographic room construction.

The camera is constructed similarly to the present cameras in its mechanical operation.


WORK AREA
20'
Crane Operator
24" Sand Filled Concrete Block Wall
Storage
24" Sand Filled Concrete Block Wall
4'x4'x6" Armor Steel Plate
Exposure Area
Operation Room
16" Sand Filled Concrete Block Wall
0.1 Drum Strorage
40'
20'
Storage Area
Budd Cameras
Entrance
4'x4'x6" Armor Steel Plate Below
2'x4'x2" Armor Steel Plate Welded on Top
24" Sand Filled Concrete Block Wall
Storage
Area
20'
WORK AREA



Cross Section through No 6 Finishing Building


SAND FILLED WALLS 25'0" HIGH
S
9'0" SAND
Work Area
For Co 60
Casting
Center
PROCESSING
AREA
E
W
Work
Area
Source
Tube
32'6"
77'-8"
97'-0"
Control
Room
Control
Cable
3'0"
22'0"
20'0"
11'4"
2'0"
3'4"
9'0" SAND
N
4'0"
27'0"
10'0"
71'-0"
112'0"
CONCRETE BLOCK WALLS - MORTAR FILLED
25'0" HIGH
— GENERAL PLAN —
NEW BETATRON - G.S.I.

On August 1, 1962, Nuclear Consultants conducted a radiation survey of our radiographic facility. A copy is attached under 313R-6A.

In the interim period no changes have been made in building construction, radiographic procedure, equipment source type or size.

The work load will be approximately the same in 1969 as it was in 1968.

On August 1, 1962 a radiation survey was performed of the radiographic Exposure Facility at the Granite City, Illinois Plant of General Steel Industries. This survey was performed during exposure of 2 Co-60 sources from 2 Budd Company Unitron Model 110A8 units, which were arranged in several different typical operating positions.

The results of this survey show a high reading on the external walls of 1.2 mr/hr at 1 meter above the floor at the wall nearest the exposure location. The average reading, including background, was 0.15 mr/hr. Most readings did not exceed the background level of 0.05 mr/hr.

The survey of the "operations" room inside the radiographic exposure facility was 1.35 mr/hr at floor level directly at the door. The average reading, including background, was 0.30 mr/hr. Background levels of 0.05 mr/hr were found in this room. This room is entirely contained in the restricted area and is used by monitored personnel only.

GENERAL

In compliance with the State of Illinois and Federal regulations, an area radiation survey was requested on the Radiographic Exposure Facility of General Steel Industries of Granite City, Illinois. On June 24 and August 1, 1962, a physicist from Nuclear Consultants Corporation performed surveys, the results of which follow:

I. Instrumentation. A Precision Radiation Instruments, Inc., Model 107c, Serial No. 607H geiger counter was used for the radiation survey. The ranges for this instrument are 0.04, 0.2, 2.0 and 20 mr/hr. This instrument has been calibrated with Co-60. Also, a NUCOR CS-40A "Cutie-Pie" survey meter was used to cross-check when possible, but no levels were found which exceeded the range of the geiger counter.

II. Facility and Source Description. This facility is located on the ground level of the plant. It is composed of concrete block walls 24 inches thick (minimum) and approximately 10 feet high with 3 strands of barbed wire at the top. These walls form an enclosure which is posted and always kept locked. Only qualified personnel, as named in the AEC license, are permitted access to this area. Such personnel are routinely monitored for exposure to external ionizing radiation. Additional shielding is afforded individuals inside the exposure area in the form of 4' x 4' x 6" steel armour plates, located strategically inside the facility. A sketch of this facility is attached.

The radiographic sources used in this area are 2 Budd Co. Unitron Model 110AB rollout cameras. These cameras, though portable, are used only inside the exposure facility described above. Each camera contains a nominal 300 millicuries of Co-60. They are designed and approved by the A.E.C. to handle up to 10 curies of Co-60. We will be using a maximum of 300-1000 mc Co-60. Each camera has approved locking devices.

III. Operation. The Unitron 110AB rollout cameras are operated remotely by means of a 25 foot extension control from behind the armour plate shielding. The source positioning tubes are located in proper exposure position prior to unlocking the Unitron cameras. Such cameras are then unlocked, after which the radiographer retires to a location behind the armour plate shielding from which location the sources are "run-out" into exposure position. He then retired to the operations room where he waits until the exposure is completed. At this time, still behind the armour plate, he proceeds to retract the sources into the cameras. The cameras are then locked until the next use.

Prior to any entry into the exposure area, the individual entering must monitor the area, and the cameras, with a survey meter to assure that all sources are contained within their shields. Additionally, no exposure is made without turning on the red warning lights located on each corner of the facility. For use in emergency, a phone is located inside the operations room. Since the outer door is locked from the inside during exposures, no inadvertent entry to the area is possible.

VI. Radiation Survey. Following are the results of the radiation survey performed on this facility.

A. Exterior Surfaces, Unrestricted Area.

1. Exterior readings in storage areas and passageway.

1.1 On the surface of the floor at the outside walls the average level was 0.08 mr/hr. A maximum level of 0.12 mr/hr was found immediately outside the entrance door.

1.2 At 1 meter from the floor at the outside walls the average level was 0.15 mr/hr. The maximum level of 1.2 mr/hr was found immediately adjacent to the source location inside the facility.

1.3 At 2 meters from the floor at the outside wall the average level was 0.23 mr/hr. The maximum level of 1.2 mr/hr was again immediately adjacent to the source location inside the facility.

1.4 Background in this area was an average of 0.05 mr/hr.

The above reported levels could be reduced to 1/4 if the Partial Occupancy factor were applied to this unrestricted area.

B. Operations Room, Restricted Area.

2. Readings inside enclosure in Operations Room.

2.1 At the surface of the floor the average level was 0.31 mr/hr. A maximum level of 1.35 mr/hr was found at the door leading into the exposure area.

2.2 At 1 meter from the floor the average level was 0.26 mr/hr. The maximum level of 1.[illegible] mr/hr was found at the door leading into the exposure area.

2.3 At 2 meters from the floor the average level was 0.33 mr/hr. The maximum level of 0.85 mr/hr was found at the door leading into the exposure area.

2.4 Background level in this room was found to be 0.03 mr/hr.

The above reported levels are found inside the restricted area which is accessible only to monitored personnel. An occupation factor of 1/2 has been found to apply for this area due to operations scheduling.

CONCLUSIONS

From the above survey the following conclusions may be drawn:

I. The existing facility is suitable for use for the radiographic procedures outlined in the AEC licensing request of March 7, 1962 (AEC 313) and subsequently approved on AEC license #12-3271-1. Such use will not result in exposure to non-occupational personnel in excess of the limits specified in Title 10, Code of Federal Regulations, Part 20.

II. Normal usage of the Operations Room located in restricted area should not result in exposure to radiographers in excess of the permissible limits specified in Title 10, Code of Federal Regulations, Part 20 for occupationally exposed personnel. Indeed, if present occupancy factors continue, these individuals should not receive whole body exposures in excess of approximately 1/16 of the permissible limits during a normal 40 hour work week.

This report is respectfully submitted.

6. (b) DESCRIPTION OF RADIATION DETECTION INSTRUMENTS TO BE USED

We have two model CS-40A Nucor Survey Meters, serial numbers 1207 and 1193 manufactured by the Nuclear Corporation of America, and one survey meter Model 592B serial number 3432 manufactured by the Victoreen Instrument Company.

A general description of the instruments and their operation follows: A more specific method of operation is described in the operating procedure.

The Nucor Model CS-40A Survey Meter is a portable, transistorized ionization chamber type instrument for the detection and measurement of nuclear radiation caused by the presence of beta and gamma type radioactivity. It consists of an air ionization chamber, a high-grain transistorized DC amplifier, a transistorized power supply and a large 4-1/2 inch indicating meter. The instrument is contained in an aluminum instrument case measuring 10" x 4-1/2" x 4-3/4". The instrument ranges are 0-5, 50, 500, 5,000, and 50,000 mr/hr. The instrument is powered by a single Mercury battery (Mallery type RM-42R or equivalent) providing an operating life in excess of 500 hours. For ease of maintanenace and fabrication the instrument has been constructed in three sub-assemblies namely: (a) Probe Assembly, (b) Amplifier, (c) Power Supply Assembly.

Operation of the CS-40A is extremely simple. The instrument has been calibrated and fully tested before shipment and the operator need only adjust the motor ZERO ADJUST on the top of the instrument case and select the desired meter range to obtain accurate radiation measurement. In addition to the OFF and ZERO positions, five ranges on which the meter reading is multiplied by 10,000, 1,000, 100, 10 and 1 are provided giving the instrument the ability to measure fields ranging from 1 mr/hr to 50 mr/hr. To set the CS-40A into operation, simply turn the selector switch into the ZERO position. This applies filament voltage to the electrometer tube and power to the time delay circuit. Approximately 1.5 seconds after this voltage has been applied, the power oscillator is energized and all required voltages are applied to the instrument. In this position, the ZERO ADJUST control should be adjusted for a zero meter reading. It is to be noted that in this position the instrument may be zeroed in a radioactive field of any intensity without effecting the calibration of any of the five ranges. When meter zeroing has been accomplished, turn the selector switch to the X10,000 position. In taking measurements, it is always desirable to have the selector switch set on the position which gives a near mid-scale deflection. This switch has been designed so that the first position encountered provides the highest sealing factor. This prevents the possibility of meter damage which could result from an excessive amount of radiation sending the meter pointer rapidly off scale. After it has been determined that the amount of radioactivity is not sufficient to reflect the needle near mid-scale, turn the selector switch to lower ranges until the deflection is such that the most accurate reading is obtained. The reading times the scaling factor is the amount of radioactivity present in milliroentgens per hour. A meter sensitivity control is provided at the bottom of the instrument for calibration of the CS-40A. However, this control has been preset and normally will not require readjustment unless components, other than the battery are replaced. Re-calibration should not be attempted unless a known source is available and the proper method known. The screw-driver adjustment on the top of the meter is also preset and should not be moved unless the meter needle indicates something other than zero with the selector switch in the OFF position.

The Victoreen Model 592B Survey Meter is a battery operated ion chamber instrument for the measurement of X and gamma radiation over the range of 1 to 1000 mr/hr. Three linear ranges with full scale sensitivities of 1000, 100 and 10 mr/hr are provided. A rugged fiberglass reinforced case house the component and ion chamber assembly. The case has a top and bottom section held together by two dzus fasteners. The meter, two controls and a carrying handle are on the top surface of the instrument.

The meter is graduated from 0 to 10 mr/hr. The OFF-ON range selection switch knob and zeroing control knob are located to the left and right of the carrying handle at finger tip reach. Three range positions, X100, X10 and X1, are marked on the case top. A guard ring protects the zeroing knob against accidental displacement.

Reference data:

a. Range 0-10, 0-100, 0-1000 mr/hr.

b. Energy range is 50 kev to 1.3 mev.

c. Accuracy is 10% at full scale (0.50 to 1. 3 mev)

d. Battery complement. Three RM-4 mercury cells 1. 3 volts each. Six number 412 Eveready 22.5 volt batteries.

e. Battery life 300 hours.

f. Weight 4-3/4 pounds.

g. Dimensions: 9-7/8 inches by 4-11/16 inches by 4-1/4 inches.

h. Tube complement: One 5886A, one CK5470X and one VS10.

Operating Steps of the Model 592B

a. Turn the range to zero position.

b. Adjust the zero control so that the meter reads exactly zero. In the zero position, the input has been switched to a reference potential and the instrument has been switched to maximum sensitivity X1, which allows accurate zeroing in a radiation field.

c. Turn the range switch to the X100, X10 or X1 range as required and the instrument will measure gamma radiation in mr/hr.

Each time the instrument is turned off it is advisable to zero the switches again when a new measurement is made using the X100, X10 ranges. This applies to situations when frequent measurements are made as in surveys.

6. (c) INSTRUMENT CALIBRATION PROCEDURES

The two Nucor CS-40A and the Victoreen Model 592B survey instruments are calibrated by St. Louis Testing Laboratories, Inc., 2810 Clark, St. Louis, Missouri 63103. The President of this corporation is Mr. C. D. Trowbridge.

St. Louis Testing Laboratories, Inc. uses a Co 60 isotope of 15 to 25 mc. A minimum of two checks are made on each scale of the survey meter in the range of 1.0 to 4000 mr/hr. A statement of calibration is affixed to the meter at the time of the check. In addition, a formal certification of calibration is submitted to GSI. If the instrument is out of calibration, it is repaired and recalibrated.

6. (d) PERSONNEL MONITORING EQUIPMENT

We have two Victoreen Minometers, serial numbers 387-2140 and 901 (model No. 687C), used in conjunction with 13 pocket chambers model 3A. The pocket chambers are also manufactured by Victoreen and cover the range of 0-200 mr. In addition, we have two Bendix dosimeter charges Model 906, serial numbers 01012 and 00533 used in conjunction with 24 pocket chambers model No. 638. The pocket chambers are also manufactured by Bendix Corp. and cover the range of 0-200 Roentgens. In addition, we have 4 personnel radiation monitors Model RT-1 manufactured by the Eberline Instrument Corp.

Film badges are supplied by the R. S. Landauer, Jr. & Co., 3920 - 216th Street, Matteson, Illinois, area code 312. Each individual has his own film badge and the film badge report becomes the permanent record of the individual's exposure. Forms AEC 4 & 5 are maintained for each individual.

Blood counts under the supervision of GSI's physician, Dr. J. F. Brennan, are taken at time of employment and separation.

6. (e) OPERATING AND EMERGENCY PROCEDURES

General Steel Industries, Inc.
Operation Procedure for Use of Cobalt 60 Radiographic Sources

All "Radiographers" (as defined in Title 10, Part 31), 24-MEV Betatron, shall:

1. Read and understand Parts 20 and 31 of Title 10 of the Code of Federal Regulations.

2. Read and become well acquainted with the Instruction Manual for the Budd roll-out camera device and the Radionic Panoramic camera.

3. Read and retain a copy of these Operating Procedures and the attached Emergency Operating Procedures.

4. Receive instructions in the operation of the exposure device and receive actual experience in its operation.

5. Receive instructions and procedures from Mr. H. B. Norris.

6. Receive instructions in health physics, monitoring and personnel monitoring and dosimetry from a physicist from Nuclear Consultants Corporation, or other source including GSI personnel.

Above instructions will include lectures, actual use of exposure devices and survey instruments, and practical problems, utilizing Appendix A, Part 31, Title 10, CFR, as an outline. A copy of this training program is attached as 6(f).

There will be no transportation of sources or exposure devices to any field location, nor in fact, shall they be moved from the special radiographic room within the plant. All records will be maintained by Mr. H. B. Norris or by the division accountant (inventory) in the division accounting department at the same address.

Only "Radiographers" licensed by the AEC and assigned to this department shall have keys to the radiographic room and to the exposure device. Under NO conditions are you to loan or give your key to anyone, regardless of his position within the company without the direct approval of Mr. Norris. If your keys are lost or misplaced, notify Mr. Norris of this at once.

All "Radiographers" must wear film badges whenever working around radiation whether it be x-ray, betatron or the Co 60 sources.

They must also wear the pocket chambers provided when working with the Co-60.

A step-by-step procedure which is to be followed by each shift and each man is tabulated below:

1. Unlock the door to the radiographic room from the outside, enter and immediately lock the door from the inside. This is necessary due to the higher than normal noise level in the plant. A loud siren is located over the door with a push button activator on the outside for use in the event another radiographer must enter the room while it is locked from the inside.

2. Place film holder and any other equipment taken into the room in the small viewing room outside the radiation area (but within the radiographic room). Using the NRD Model CS-40A survey meter, make an entrance survey of each exposure device (Budd Company's Model 110A Unitron Radiographic Camera), making certain no sources are exposed.

3. Make the necessary entries in the Utilization and Survey Log. (See attached sample of log.)

4. Set up exposure film and fix position of source tube. Always place source as near center of room and as far from the walls as is practical. Never place source closer than four feet from the wall unless it is inside the casting. Make certain source tube is firmly fixed in position required, and that any angle in tube is not too sharp to prevent easy operation of source within the tube.

5. Turn on red warning lights. These lights are strategically located on the top of the exposure room walls, and over the outside entrance, so that they may easily be observed by any personnel passing by the area adjacent to the exposure room.

6. Unlock Budd Camera devices.

7. Have castings and camera located so that the control cable may be operated from behind one of the 4 inch thick armor plate steel shields separating the radiographic area from the control area. The control cable shall be maintained behind this shielding at all times. The source may now be exposed utilizing the control cable from behind the armor plate shields. Observe the source position indicator.

8. Make necessary entries in Utilization and Survey Log.

9. "Radiographer" retires to small room outside of radiation area to time and wait for exposure to be completed. At no time should he enter the exposure area (forward of the steel shields) when sources are exposed.

10. After exposure is completed, retract source into source holder with control cable from behind armor plate shielding.

11. Make an operational survey of the entire area, taking special note of source tube and camera device.

12. Lock camera device. This should be done even though a second exposure is to be performed within the next few minutes.

13. Make necessary entries into Utilization and Survey Log. (See attached)

14. Turn off warning light.

15. Steps No. 3 to No. 14, inclusive, may be repeated from two to five times before going to lunch, or between trips to the darkroom and film storage area, or the end of the shift. Darkroom and office are over 500 yards from exposure room.

16. Before leaving the room, whether to go to lunch or darkroom or at the end of the shift, a final survey of source holder and source tube will be made and noted in the log. Be sure to sign the log.

17. Leave exposure room and lock door from the outside. Never leave room, even for a few minutes, without locking from the outside.

18. A final dosimeter reading will be made and recorded at the end of each shift. Film badges as noted above will be worn throughout the eight hour shift, regardless of work being performed.

19. See Emergency Procedure for proper action in case of an emergency. In case of emergency follow those procedures and call Mr. Norris at once. His telephone number shall be known to all radiographers and is always on file in the company guard house which is open 24 hours a day, 7 days a week.

Operating Procedure for Use Of Cobalt 60 Radiographic Source In The Betatron Room

All radiographers must wear film badges and pocket chambers provided whenever working around penetrating radiation, whether it be from the Betatrons or the Co 60 sources.

1. Unlock the door to the Control Room from the outside, enter and immediately lock the door. In the event another radiographer must enter the Control Room while it is locked, he will have to knock on the door.

2. Using the NRD Model CS 40A or the Victoreen Model 592B survey meter, make an entrance survey of exposure device (Radionic Panoramic Camera Model P60-100-A) making certain no source is exposed.

3. Make the necessary entries in the utilization and survey log.

4. Always place the casting as far south as the handling crane will permit, approximately 54' from the north wall. The casting will be as close as is practicable to the east wall. Set up the exposure film and fix the position of the source tube. Make certain the source tube is firmly fixed in the position required and that any angle in the tube is not too sharp to prevent movement of the source within the tube. The Co 60 camera will be set approximately 3' from the east wall and 32' from the north wall. The control crank unit will be inside the control room.

5. Turn on red warning lights. These lights are strategically located at the entrance door to work area and at the double leaf door. Lights may easily be observed by any personnel passing by the area adjacent to the exposure room.

6. Unlock the Radionic's camera device.

7. Have casting and camera located so that control cable may be operated from inside the control room. Observe the source position indicator.

8. Make the necessary entries in utilization and survey log.

9. Radiographer returns to the Control Room outside the radiation area to time and wait for the exposure to be completed. At no time should he enter the exposure area (forward of the 10'0" thick sand filled wall) when the source is exposed.

10. After the exposure is completed, retract the source into the camera by means of the control cable from inside the control room.

11. Make an operational survey of the entire area, taking special note of source tube and camera device.

12. Lock camera device. This should be done even though a second exposure is to be performed within the next few minutes.

13. Make necessary entries in the utilization and survey log. (See attached)

14. Turn off warning lights.

15. Steps No. 3 to No. 14 inclusive may be repeated several times before going to lunch or the end of the shift. Darkroom and offices are located in the processing area behind the 10' 0" thick sand filled wall.

16. Before leaving the room, whether to go to lunch or darkroom or at the end of the shift, a final survey of source holder and source tube will be made and noted in the log. Be sure to sign the log.

17. Leave exposure room and lock door from the outside. Never leave room, even for a few minutes, without locking from the outside.

18. A final dosimeter reading will be made and recorded at the end of each shift. Film badges as noted above will be worn throughout the eight hour shift, regardless of work being performed.

19. See Emergency Procedure for proper action in case of an emergency. In case of emergency, follow those procedures and call Mr. H. B. Norris at once. His telephone number shall be known to all radiographers, and is always on file in the company guard house, which is open 24 hours a day, 7 days a week.

EMERGENCY OPERATING PROCEDURES

A telephone is located in the small room protected from the radiation area but within the locked exposure room. Any deviation from normal operating procedure may be reported to the supervisor in charge of radiography without the necessity of the radiographer leaving the locked exposure room. All men handling the source will be radiographers within the definition of Part 31, Paragraph 31.3.

EMERGENCY NO. 1 SOURCE CANNOT BE RETRACTED INTO THE SOURCE HOLDER OR THE SURVEY INDICATES THAT IT IS NOT WITHIN THE HOLDER WHEN IT SHOULD BE. THE RADIOGRAPHER ON DUTY SHALL:

1. The warning lights will be on in conformance with operating procedure. If the emergency happens at any other time, turn on warning lights.

2. Call H. B. Norris, by auto call or telephone.

3. Unlock door, leave radiation room, and lock door from the outside.

4. Using NRD Model CS 40A survey meter, survey area immediately surrounding radiographic area, and post any area of greater than 5 mr/hr.

5. Maintain vigilance at doorway until Mr. Norris arrives.

THE RADIATION SAFETY OFFICER SHALL

1. Obtain full story, evaluate, rectify if possible.

2. If necessary, call Nuclear Consultants Corporation or the Budd Company. Exposure room will remain locked and all warning lights will remain on until area is safe. Radiographer will maintain personnel vigilance at exposure room door if gravity of situation warrants.

3. Record will be made of the incident.

4. AEC will be notified, if necessary, in compliance with Title 10, Part 20, Paragraph 20.403.

EMERGENCY NO. 2 POCKET DOSIMETER READS OFF SCALE

1. Do not extrapolate.

2. Recharge dosimeter, check it after 15 minutes, repeat this step. If it reads off scale both times, it is probably faulty.

3. Develop casting exposure films, see if they have the correct density with no distortion. Any misalignment of source or source tube that could result in overexposure would not give a satisfactory radiograph.

4. Check survey instrument. If survey instrument and radiographs prove to be all right and dosimeter indicates a faulty discharge, assume dosimeter to be faulty. Use spare dosimeter.

5. Call H. B. Norris and notify him of these results for his evaluation before making any other exposures.

6. If above indicates that the apparent overexposure may have actually occurred, send film badge in for processing with request for an immediate reply by telephone.

7. If film badge report substantiates dosimeter reading, the radiographer will be sent to the corporation doctor with a full report.

8. AEC will be notified in conformance with Title 10, Part 30, Paragraph 20.403.

6. (f) TRAINING PROGRAM

Date	Entrance Survey	Source Time				Operational Survey				Final Survey	Holder Locked		Casting		Radio-grapher
		No. 1		No. 2		No. 1		No. 2					Pattern No.	Serial No.	
		Out	In	Out	In						1	2			

Radiation Safety Training Program for Industrial Radiographers at
General Steel Industries - Granite City Plant

Conducted by: Messrs. William E. Davis - Plant Metallurgist
Robert W. Ripley - Asst. Plant Metallurgist
H. B. Norris - Manager of Quality Control
J. T. McCrone - Gen'l Foreman Nondestructive Testing
P. Lewis Frazar - Plant Safety Director

I. Fundamentals of Radiation Safety

A. Radiation - 4 hours

1. atomic structure
2. isotope and radiation
3. alpha, beta and gamma
4. interaction with matter
5. x-radiation and gamma radiation

B. Glossary - 2 hours

1. terms - learn them first
2. significance and explanation of

C. Radiation Levels - 2 hours

1. unrestricted area, define, explain dangers in
2. radiation area, define, explain dangers in
3. high radiation area, define, explain dangers in

D. Health Hazards from Radiation - 2 hours

1. whole body effects
2. reversibility and irreversibility
3. skin effect
4. reproductive organs - genetics and future generations
5. effect on blood

E. Betatron - 2 hours

1. theory
2. operation of
3. hazards of
4. radiation from
5. comparison with gamma from Co 60
6. safety devices, procedure and explanation of

F. Methods of Controlling Radiation Dosage - 3 hours

1. time
   a. equations
   b. explanation

2. distance
   a. equations
   b. explanation

3. shielding
   a. equations, charts and graphs
   b. absorption factors
   c. half value layers

II. Radiation Detection Instruments - 3 hours

A. Radiation Detection Instruments

1. Nucor CS 40A survey meter
   a. principle of operation
   b. operation technique
   c. limitations
   d. calibration

2. Film Badge
   a. principle of
   b. use of
   c. limitations

3. Victoreen Minometer and Pocket Chambers
   a. principle of
   b. use of
   c. limitations

B. Survey Techniques - 3 hours

1. General
   a. background and its significance
   b. equations

2. Our Operation at GSI
   a. technique
   b. documentation and records

III. Radiographic Equipment - 1 hour

A. Budd Company Exposure Device

1. Diagrams
   a. explanation
   b. limitations
   c. advantages

2. Operation of
   a. theory
   b. our procedure

3. Storage Container
   a. requirements
   b. qualifications of Budd Co. Device
   c. A.E.C. requirements

IV. Procedure - 3 hours

A. Regular Operation Procedure

1. review step by step
2. explanation of

B. Emergency Operating Procedures

1. review step by step
2. explanation of

V. A.E.C. Regulations - 2 hours

A. Title 10,Part 30

1. review
2. explain

B. Title 10, Part 31

1. review
2. explain

C. Title 10, Part 30

1. review
2. explain

VI. Review - 3 hours

VII. Examination - 2 hours

VIII. Equipment and Operation Of in the Radiographic Installation Itself

A. Budd Co. Exposure Device

1. Actual operation of, by each individual until he becomes proficient in its operation.

2. Actual recording of any and all records required by A.E.C. and GSI.

B. CS 40A Survey Meter

1. Actual operation of, by each individual until he becomes proficient in its operation.

2. Actual recording of any and all records required by A.E.C. and GSI.

C. Pocket Chamber and Minometer

1. Actual operation of, by each individual until he becomes proficient in its operation.

2. Actual recording of any and all records required by A.E.C. and GSI.

D. Film Badge

1. Actual practice and full explanation of procedure of receival, use and mailing to Badge Service Company.

2. Explanation of records required by A.E.C. and GSI.

IX. Four weeks on the job training as an assistant radiographer.

X. Evaluation utilizing attached "Radiographers Training Evaluation Form".

PERIODIC TRAINING

Periodic training falls into two categories. The first involves possible changes in equipment, technique, procedure, and AEC regulations, which, by their very nature makes it mandatory that the radiographer be fully informed, trained, and competent. The occurrence of these changes is completely unpredictable. When and if they occur, each radiographer will receive all necessary training.

REFRESHER INSTRUCTION

The second category consists of refresher instruction in radiation protection. The radiographer will be given a test, similar to the sample previously submitted, once each year. If an individual's grade drops below 20% of his previous test grade, he will receive 8 hours of refresher instructions covering the area of weakness exposed by his test grade. He will be given a retest. All test results will be filed for AEC inspection.

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5. Los Alamos Handbook of Radiation Monitoring
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   S. T. Cantril, M.D.
   H. M. Parker
   Argonne National Laboratory

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    S. T. Cantril
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    Gerald H. Tenney
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    Edward Spaena, Ph.D.
    Scientific American

13. General College Chemistry
    L. B. Richardson
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A. Morrison
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17. Radiation Physics & Bomb Phenomenalogy
U. S. Government Printing Office

18. Concrete as a Protective Banner for Gamma Rays from Cobalt 60
R. J. Kennedy
H. O. Wyckoff
W. H. Snyder
National Bureau of Standards
U. S. Government Printing Office

19. Title 10 Atomic Energy Part 20 Standards for Protection against Radiation
Code of Federal Regulations

20. Title 10 Atomic Energy Part 30 Licensing of Byproduct Material
Code of Federal Regulations

21. Title 10 Atomic Energy Part 31 Radiation Safety Requirements for Radiographic Operation
Code of Federal Regulations

22. Electron & Nuclear Physics
J. B. Hoag, Ph.D.
D. Van Nostrand Company, Inc.

PART III - SAMPLE TEST

SAMPLE TEST

1. A 10 curie cobalt source is to be used in the center of a 20 ft. square room constructed with 24 inch concrete walls. What is the radiation intensity at:

    1. the inside surface of the wall.

    2. the outside surface of the wall.

        a. use 3" as H.V.L. for concrete
        b. output of 14,400 mr/hr/curie at 1 foot

2. If a survey meter shows a 2 mr/hour gamma radiation level from Co-60 and a man is in this one for 2 hours, what radiation dosage will he receive?

3. If the Nucor survey meter reads 3 and the range scale pointer is on 100X what is the radiation level? 1X? 10000X?

4. Radiation Exposure Dosage may be reduced by three methods. What are they?

5. Explain the term 5 (N-18)

6. What are the 3 primary parts of an atom?

7. List everything you can from the expression 27 Co-59.

8. Describe and discuss alpha, beta and gamma radiation.

9. Granite City, Illinois is in regional office area number________________ with operation offices in______________________________.

10. Define to the best of your ability-

    a. H.V.L.
    b. inverse square law
    c.. isotope
    d. half life
    e. gamma radiation
    f. ion
    g. background radiation
    h. curie
    i. millicurie
    j. ionization

PART IV

RADIOGRAPHERS TRAINING EVALUATION SHEET

RADIOGRAPHERS TRAINING EVALUATION FORM

NAME________________________________ AGE__________ DATE______________

1. Lecture Test Grade______________________________

2. Text Book Test Grade______________________________

3. Participation during lecture course______________________________

   Comments______________________________
   ____

   As observed by:______________________________

4. Proficiency at the end 4 weeks in operation of:

	Good	Adequate	Poor
A. Budd Co. Unitrons	____	____	____
B. Radionic Camera Model P60-100-2	____	____	____
C. CS-40 A survey Meter	____	____	____
D. Victoreen Minometer & pocket chamber	____	____	____
E. GSI Operating Procedure	____	____	____
F. Simulated Emergency Procedure			
Number 1	____	____	____
Number 2	____	____	____
G. Utilization log	____	____	____
H. Personnel Monitoring Records	____	____	____

5. Comments______________________________
   ____

6. Recommendations:
   A. Additional 2 weeks "on-the-job training"______________________________
   B. Additional academic knowledge______________________________
   C. Qualifies as Radiographer______________________________

SIGNED______________________________ ______________________________
TRAINEE RADIATION PROTECTION OFFICER

6. (g) INTERNAL INSPECTION SYSTEM OR OTHER MANAGEMENT CONTROL

(h) OVERALL ORGANIZATIONAL STRUCTURE

The Granite City Plant Management Control System was set up to assure management as well as the A.E.C. that all A.E.C. and Management regulations, provisions, and operating procedures are fulfilled by all personnel concerned.

The control group is headed by Mr. R. L. Lich, President and General Manager of the Granite City Plant. Mr. Thomas Ditchfield is the Vice President-Manufacturing reporting to Mr. Lich. Mr. H. B. Norris, Manager of Quality Control, is the radiation protection officer in direct supervision of all radiographic procedure and safety. He reports to Mr. Ditchfield, who is responsible to Mr. Lich.

Mr. Paul Wertley, Plant Accountant, is responsible to the Vice President-Manufacturing. His department operates independently of the nondestructive testing group. Mr. Wertley supervises the actions of Mr. Howard Wigger who conducts quarterly inventories, maintains records, and operates a pull-out file to insure compliance with Title 10, Part 31, concerning calibration of survey instruments and leak tests. He maintains the following records:

1.	Radiation survey instrument calibration records	31.104
2.	Leak tests certificate	31.105
3.	Quarterly inventory records	31.106
4.	Utilization log	31.107
5.	Film badge reports	31.203
6.	Pocket dosimeter reports	31.203
7.	Radiation survey records	31.303
8.	Blood count records	----

In addition, the Plant Safety Director, Mr. P. Lewis Frazar, who is responsible to Mr. Russell Crecelius, Plant Personnel Director, works in close association with Mr. Norris. Through Mr. Crecelius, the Illinois State Board of Health is advised of radiation safety and operating procedures. Correspondence is maintained with State Board of Health in matters relating to A.E.C. license applications, and radiation instrumentation, as well as their own requirements.

In the routine of a day's operation, Mr. Norris has direct contact with the radiographers on duty. Mr. Norris is a nondestructive testing engineer, having graduated from the University of Wisconsin at Madison, Wisconsin. His background included consulting work for the A.E.C. He has spent over twenty years in nondestructive testing including time in charge of all nondestructive testing at Allis-Chalmers Manufacturing Company and also time at the Los Alamos Scientific Laboratories in the nondestructive testing group. He has also been active in the National Society for Non-destructive Testing. He is at present directly responsible for all phases of radiography at the Granite City Plant. This includes two 24-mev betatron installations, three Co 60 isotopes and two low voltage x-ray machines.

The pocket dosimeters are read and recorded atleast once each day, and the radiation survey record is maintained in compliance with Part 31.303a, b and c. Film badge reports are studied, recorded and filed each week. Operating and Emergency procedures are known by each radiographer. Copies of these procedures are maintained in the gamma ray enclosure office and in the radiographer's office.

Mr. P. Lewis Frazar, Plant Safety Director, arranges individual blood counts. These tests are performed by the Clinical Laboratories, St. Louis, Mo., and their report is received and evaluated by Dr. J. F. Brennan, Granite City Plant Physician, at the plant dispensary. Those reports are also recorded and a file maintained.

In summary, three separate departments report on different, but well defined, aspects of radiation safety to the Vice-President-Manufacturing, thus, acting as checks on each other.

Mr. H. B. Norris - Operating procedure and radiation protection.

Mr. Russell Crecelius - Medical and liaison with the State Borad of Health of Illinois

Mr. Paul Wertley - Facility inventory and records

6. (i) LEAK TESTING PROCEDURES

Leak tests are performed in accordance with Part 34, Section 34.25 by St. Louis Testing Laboratories, Inc., 2810 Clark, St. Louis, Missouri 63103. St. Louis Testing Laboratories conduct these tests under license #24-00188-03.

Enclosure III

A knowledge of fundamental atomic structure is an essential prerequisite to any study of nuclear radiation.

As is well known all matter is composed of atoms which, in turn, consist of nuclei surrounded by one or more electrons. These electrons are often called planetary electrons because they are assumed to revolve around the nuclei in somewhat the same manner as the planets in our solar system revolve around the sun. Whether or not they do actually revolve in this manner isn't important, but by assuming they do we can explain many things.

The concept that matter is discontinuous, that it is made up of particles, can be traced back as far as 1000 B.C. Some of the ancient Greek philosophers favored this view and one of them Democritus is usually given credit for the first atomic theory. It is surprising that many of his ideas would be fairly creditable today if they were but slightly modified. He assumed that there are as many kinds of atoms, (ultimate particles) as there are varieties of matter, he made no distinction between atoms of elements and "atoms" of compounds. Other Greeks, notably Aristotle, did not find the atomic concept of much value in their philosophy of the natural world and because of his great influence the atomic theory was abandoned for the next 1500 years or so. During the Renaissance, Robert Boyle and Isaac Newton revived the atomic theory and Niels Bohr the man who gave the modern concept of the atom and originated the method we now use to picture the atom died only a few months ago.

So we may form a mental image of a sort of miniature solar system, the atomic nucleus representing the sun, the revolving electrons, the planets. A few comparative figures may help establish the image more firmly in the mind. Our solar system is some 4,000,000,000 miles in diameter while the diameter

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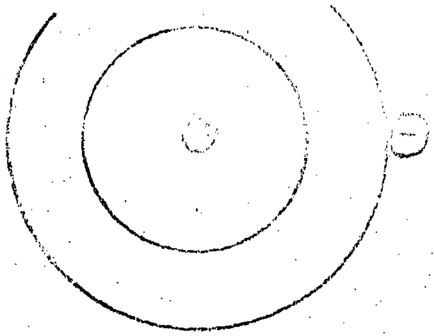
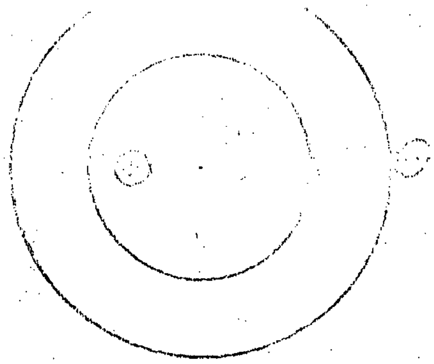
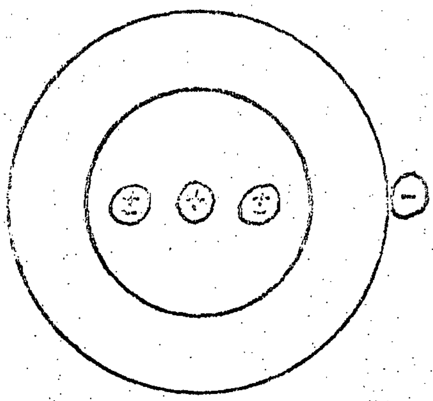


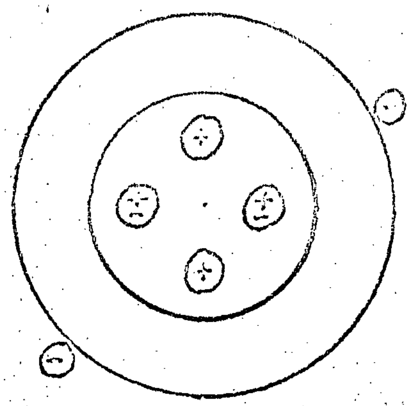
Hydrogen Atom
one proton
one electron



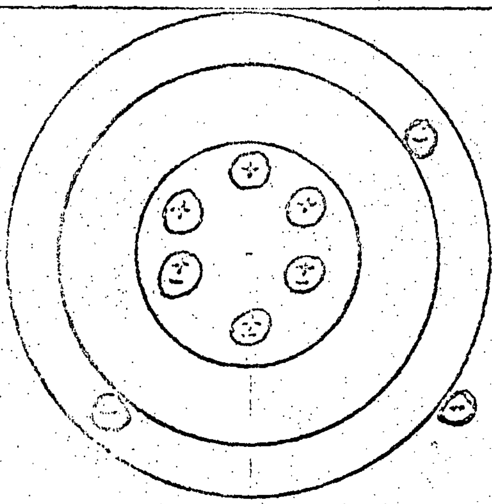
Deuterium Atom
one proton
one neutron
one electron



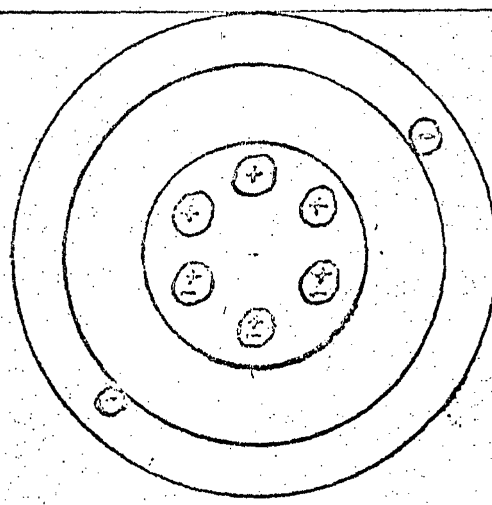
Tritium Atom
one proton
two neutrons
one electron



Helium Atom
two protons } Alpha
two neutrons } Particle
two electrons



Lithium Atom
three Protons
three neutrons
three electrons



Lithium $^{+}$Ion
three Protons
three neutrons
two electrons

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of an atom is about 100,000,000th of a centimeter, (which is about .4 of an inch).

Now the nucleus is so small that it would take 100,000 nuclei, side by side, to span this atomic diameter. Again compared with our solar system, only 7300 suns placed side by side would span the solar system diameter. As in the solar system, the sun is far heavier than all of the planets together, so in the atomic system the nucleus is heavier by far than all the orbital electrons together. In all the atoms, except hydrogen, the nucleus outweigh by more than 3700 times all its orbital electrons together. The atom, therefore, consists mostly of space, a tiny incomprehensibly dense nucleus surrounded by electrons at relatively great distances from it.

The density of the nucleus is another figure that we can comprehend only by comparison with a more familiar object. Mathematically, we can express the density of the nucleus as follows: 2.4×10^{14} grams per CM^3. This has little significance unless we picture a single cubic centimeter, (1/16 cubic inch) of a material of this density, place it on a scale, through our powers of imagination, and discover that it weighs 240,000,000 tons. This will fatigue the most fertile imagination.

To continue our comparison of an atom and solar system, we will next take up the force that holds them together. In the solar system, the planets are bound to the sun by the force of gravity, whereas in the atom the corresponding force is electrical. The electrons all possess negative charges. The nucleus of the atom is always positively charged. Since opposite electrical charges attract, the electrons are kept in their orbits by the attractive electrical force between the nucleus and the electrons.

We may not be incorrect in saying that atomic energy is a misnomer. Atomic energy is chemical energy, the type of energy we have all been familiar with for all our lives. It is the energy released in combustion for instance.

are often capable of great wrath and fury. The devastation of Hiroshima and Nagasaki bear ample witness to what happens when the nucleus is disturbed.

It should, therefore, follow that what has been called atomic energy is actually nuclear energy. The term atomic energy has come into such general use, however, that it has gained wide acceptance even in scientific circles, and so we have the United States Atomic Energy Commission, which is really concerned with the development of nuclear energy.

Until recently the total number of known elements was thought to be 92, with hydrogen (H) the lightest, and uranium (U) the heaviest. Now, over 100 elements have been identified.

All atoms except ordinary hydrogen contain primarily three elementary particles; the neutron and proton which are in the nucleus, and the electron revolving in orbit around the nucleus. Ordinary hydrogen doesn't contain a neutron. See Table I for characteristics of these particles.

During the past two decades the idea of an atom consisting of three primary particles exploded along with the atom itself, dozens of new particles have been discovered, and particles such as the neutron are now thought to be much more complicated and complex than the old (20 years ago) theory of a negative and positive charge. However, for our purpose we will continue to use the old theory.

TABLE I

Name	Symbol	Electrical Charge	Mass
Electron	e	Negative -1	0.000548 mu *
Proton	p	Positive +1	1.007575 mu
Neutron	n	None 0	1.00893 mu

* An atomic mass unit (mu) is 1.6×10^{-24} grams or .000,000,000,000,000,000,000,001,6 grams

Chemical energy arises from the configuration of the electrons surrounding the nuclei; these electrons are extremely light and nimble, arranging and rearranging themselves quite easily. These electrons lie in different groups about the nucleus, there may be more than one in the same orbit (unlike our solar system in which there is only one planet per orbit) and there are many orbits or "energy levels". As more and more electrons are added to an energy level it becomes full and other energy levels are formed, filled with electrons and this process continues until we have the heaviest elements formed.

The outermost electrons, therefore, may be removed to a considerable distance from the nucleus. The nucleus does not attract the outer electrons as strongly as those that lie in groups near the center. The electrons in the outermost energy level possess the highest energy, those in the energy level nearest the nucleus the lowest.

The chemical reactions of elements are a result of the electron configuration. For all except the light elements, hydrogen and helium, the outermost group of electrons require eight electrons. If this group contains only one, two or three electrons, the atom is more likely to lose these to some other atom that attracts them more strongly. If the outermost group contains six or seven electrons the tendency is to acquire one or two electrons. If like argon the outermost level contains 8 electrons it is chemically inert. This is the basis for the formation of "ionic compounds, common table salt being a good example.

Rather than give up or attract electrons some elements with one or two electrons will combine with an element with six or seven and they will share one or two electrons, this is a covalent compound. Water is an example. So as we can see orbital electrons "get around".

The nuclei, by comparison, are dull and sluggish, but when aroused

These combinations and number of electrons vary with the element, each element has its own combination. In order to be electrically neutral, an atom must contain the same number of positively charged particles (protons) in the nucleus as negative particles (electrons) in its orbits. The removal of an electron from the orbit produces an ion pair. The free electron is the negative ion and the remaining portion of the atom, the positive ion. Drawing No. 1.

Hydrogen is not only the lightest element, but its atom is also the simplest. As shown in Drawing No. 1, it consists of a nucleus with a single electron revolving around it. The nucleus of the hydrogen atom is one of the fundamental particles of the atom, it is the proton we have already mentioned.

A study of Drawing No. 1 reveals that we have two more hydrogen atoms called deuterium and tritium, whose nuclei do contain neutrons. The nucleus of deuterium, called heavy hydrogen (deuterium and tritium in higher than natural concentrations in water (H_2O) imparts the name heavy water, primarily because it makes the water heavier than natural water) has the same charge as the nucleus of the hydrogen atom, but twice its mass. This is explained on the assumption that there exists on the deuterium nucleus another particle having the mass of the proton, but no charge. This particle is called the neutron. The deuterium atom is chemically the same as the hydrogen atom since each has the same net positive charge on the nucleus and the same number of orbital electrons (in this case one). The two atoms differ in atomic weight, deuterium being twice the mass of hydrogen and are therefore isotopes. Both are hydrogen isotopes; we do not say one is a normal hydrogen atom and the other is a hydrogen isotope. Two atoms which have the same atomic number (number of orbital electrons) but differ in atomic weight are called isotopes.

A third atom exists in nature in an exceedingly small quantity, which is likewise an isotope of hydrogen. Fig. 1. This atom contains two neutrons and one proton in the nucleus with one orbital electron. The mass of this atom is thus three times that of the hydrogen atom, although the two are chemically indistinguishable. These are naturally occurring isotopes, tritium is radioactive, emitting a Beta particle, the other two are stable.

And so we continue and atomic structure becomes more complex. Similarly, the uranium atom consists of a complex nucleus containing 92 protons, 146 neutrons, and with 92 electrons in seven different orbits revolving around the nucleus. Between these extremes, all the other atoms, iron, silver, gold, etc. consists of nuclei with varying numbers of electrons revolving around them.

The remainder of our discussion of atomic structure will be simplified by an explanation of the symbols that are commonly used.

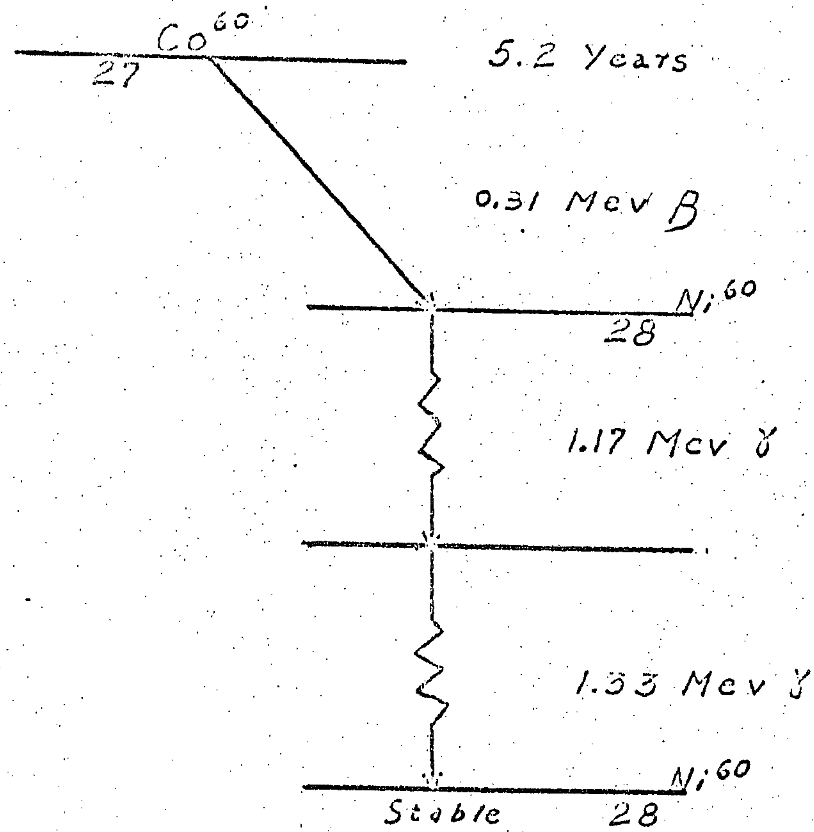
Z - Atomic number. The number of protons in the nucleus of an atom. This number identifies an element. As an example, all atoms of sodium have a Z number of 11. No other element has 11 protons in its nucleus.

A - Mass number. The sum of the protons and neutrons in the nucleus of an atom. Nearly all of the mass of an atom is contained in the nucleus.

N - Neutron number. Number of neutrons in the nucleus of an atom. A neutron has no charge and is believed to consist of a proton of + charge and and electron of - charge, the overall charge is thus 0.

If X is the symbol for an element then $_ZX^A$ is the manner in which an element is expressed. To take Cobalt for instance, it is written as $_{27}Co^{59}$. This one expression tells us that Cobalt with an atomic number of 27 + a mass number 59 has 27 electrons revolving around a nucleus containing a total of 59 protons and neutrons. If, as we should know by now, the number of electrons are equal to the number of protons, then the nucleus contains 27 protons and 59-27 or 32 neutrons.

If the $_{27}Co^{59}$ is placed in a nuclear reactor a neutron, which has no atomic number but a mass of 1 or a n^1, strikes and is captured by the nucleus



Co^{60} Spectra

of the ${}_{27}Co^{59}$. $N^1 + {}_{27}Co^{59}$ ${}_{27}Co^{60}$ we now have an isotope of Cobalt that is unstable and thus radioactive. When an atom of ${}_{27}Co^{60}$ decays it becomes ${}_{28}Ni^{60}$ in the following fashion. The ${}_{27}Co^{60}$ is now in a highly stressed and agitated state, in its effort to become stable it emits a Beta particle (electron from the nucleus). Electrons exist in the nucleus as part of the neutrons, therefore when one is expelled the neutron then becomes a + one charged particle or a proton. This atom now has one new proton plus its normal 27, a total of 28. The only element with 28 protons in its nucleus is nickel, the atom is now a nickel ion, it soon picks up an electron in its outer shell and becomes ${}_{28}Ni^{60}$ a stable isotope of Ni. Gamma rays are also emitted during this transformation, but they have no mass or atomic number. They are a result of the reorganization of the newly formed Ni nucleus. Thus it may not be incorrect to say that the cobalt decays to nickel through the medium of beta emission and the resultant nickel atom emits the gamma radiation during its first few seconds of life. Drawing No. 2.

This apparent mobility of the electrons may seem difficult to understand, so let's see if we can't explain it by an analogy.

Electrons can be removed from atoms by several means, such as heating a filament in an x-ray machine or simply by rubbing a stick of sealing wax with flannel. Some of the electrons from the atoms in the flannel are rubbed off and left on the sealing wax. Thus some of the atoms of the wax have an excess of electrons and the wax is negatively electrified, while the flannel with a deficiency of electrons is positively electrified. Under these conditions an attractive electrical force exists between the flannel and the wax and if permitted to come into contact, there will be a redistribution of electrons between the atoms of the two substances and the charge will be neutralized. This simply, is the mechanism of electrification.

It must be clearly understood, that the removal of electrons from atoms in this fashion does not fundamentally alter the nature of the atoms. Of the total number of atoms in any substance, the number that can be removed in this way or in any other way, is extremely small.

If a very large number of electrons were so removed, the electron potential between the two substances would be so great that an electrical discharge (spark) would take place to bring about neutralization. This is what takes place in a thunderstorm. It is thus an electrical force of attraction that moves the electrons. This image of a miniature solar system composed mostly of empty space, with electrons and other particles shooting hither and yon like comets through the sky will be very helpful in understanding radiation and its interaction with matter. And now before our new potential is sparked we shall proceed to the three forms of radiation emitted from radioactive isotopes. We shall explore Alpha and Beta briefly and because we will use gamma radiation we will cover it more extensively.

Radiation eminating from either naturally occurring or artifically produced radioactive isotopes fall into two categories, particle and electromagnetic. Alpha and Beta are particulate, gamma is electromagnetic.

Alpha particles are positively charged and consist of two protons and two neutrons. It is the helium nucleus, relatively heavy, about 7000 times the mass of a beta particle, and travels with an average speed 1/10 that of light. They are slightly deflected by a magnetic field and in a direction opposite to beta particles.

When a radioactive nuclei emits an alpha particle its nuclear charge, and atomic number is reducedby two units and the mass by four units. Alpha particle emission in connection with radioactive transformation is limited almost exclusively to elements of high atomic number. Alpha particles are emitted in groups with all particles having the same initial energy. Therefore, the distance that the particles in a particular group travel before losing sufficient kinetic energy that they no longer produce ionization is approximately the same. They are monoenergetic. As they move through a medium the loss of energy due to ionization occurs in small steps, each step representing the result of interaction with atoms of the medium.

If the alpha particle should happen to make a direct hit with the nucleus of one of the atoms, the nucleus may be disrupted producing artificial disintegration. Only a very few of such collisions actually occur.

The alpha particle may also be thought of as a double positive charged ion. When their velocities have been reduced greatly, they recapture their two orbital electrons and are converted to helium atoms.

The term "specific ionization" is applied to the number of ion pairs per centimeter produced by an alpha particle. Measurements reveal that this value varies with the velocity of the alpha particle and is in general higher for the lower velocities.

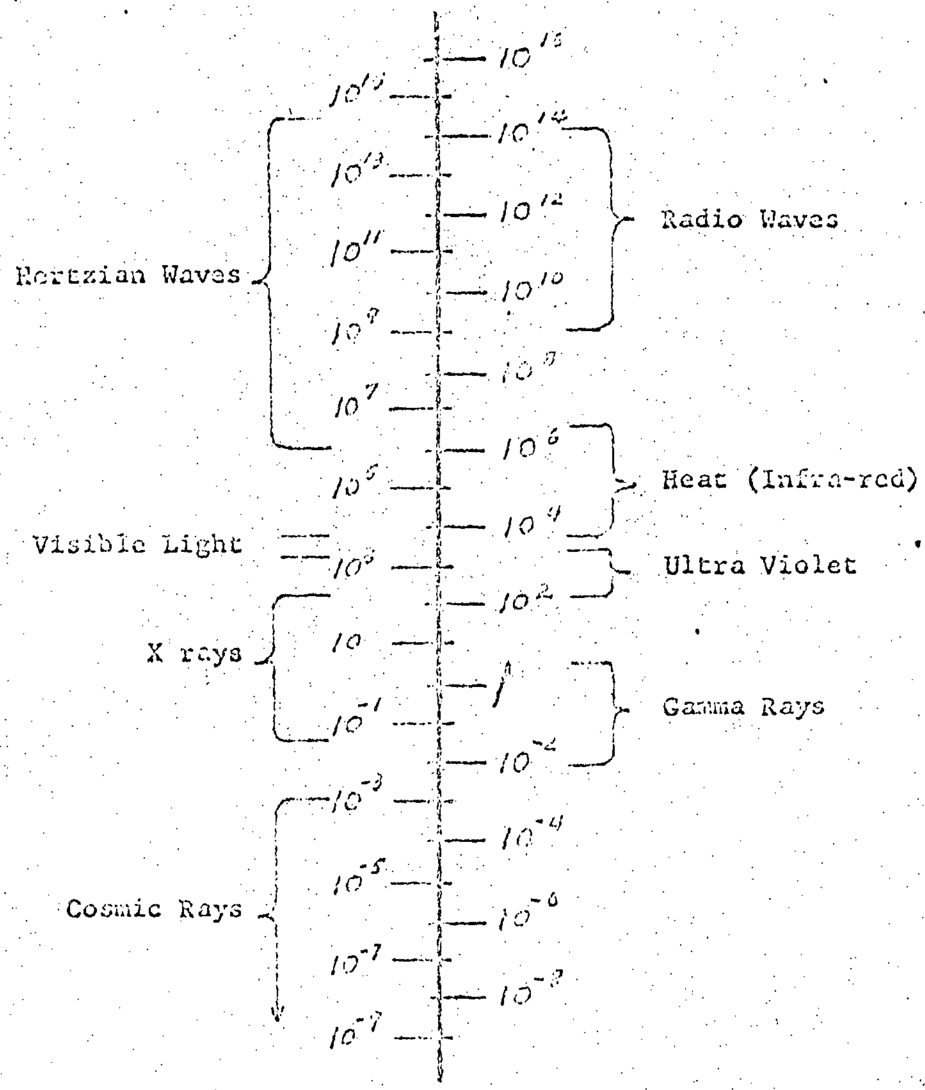
"Stopping power" is defined as the reduction in the emergent range produced when a beam of alpha particles traverses a layer of material. A sheet of mica thickness 1 mg./cm^2 will reduce the emergent range of alpha particles incident on it by approximately 1 cm in air and, therefore, has a stopping power for alpha particles of 1 cm. This power varies somewhat with the velocity of the alpha particle, the actual variation being of a greater magnitude for substances of high atomic weight.

The ease with which alpha particles may be stopped can actually be termed a drawback. If an alpha emitter is unknowingly spilled on a table top, and a coat of paint is applied, the paint will not allow the radiation to be detected. Later as the paint flakes and falls off, it may have the alpha emitter imbeded in the underside. It could thus be dangerous and exist for an extensive period of time before detection.

The most serious hazard in connection with substances emitting alpha radiation arises when these substances are taken into the body. When these substances are ingested or are otherwise assimilated into the body and are then localized by biological actions into particular tissues, these tissues are exposed at close range to the powerful bombardment of this densely ionizing radiation. If the alpha emitter does not also emit gamma radiation, there is no method of detecting its presence until its too late, unless its a material that is rapidly eliminated from the body by natural action.

Beta particles are negative charged electrons emitted by the nucleus of an atom and resulting in a nucleus with an increase of one unit of charge; the atomic number is increased one unit, and the mass number of the atom remains unchanged. In a magnetic field they are deflected to a greater degree than alpha particles. Beta radiation is not as easily stopped as alpha, are not monoenergetic, and at high energy levels travel with the speed of light. At lower energy levels the velocity is only about 20% that of light. At the same energy level they will do less damage than alpha. These beta particles form a continuous spectra of energy levels, and their quoted energy in MEV's is usually the maximum of this spectrum; the average is usually about 1/3 of the maximum.

An electron and a beta particle are identical except by definition. The term "beta ray" or "beta particle" refers only to the electrons ejected from the nucleus of an atom. Although these electrons are not considered at present to be constituents of the nucleus as separate entities, they are formed when the nucleus undergoes radioactive disintegration. Therefore, they are to be distinguished from "conversion electrons" which are also emitted by various radioactive substances but which are orbital electrons of the outer atomic structure that have been ejected by nuclear gamma rays. The properties of these two forms of radiation are identical for the same velocities of the particles. However, since gamma rays are the result of nuclear transitions from one level



ELECTROMAGNETIC SPECTRUM

The wave lengths are expressed in Angstrom Units. An Angstrom Unit is equal to 10^{-8} centimeters or .00000001 CM. An Angstrom Unit is represented by Å.

to another, they are emitted with sharply defined energies, and this accounts for the conversion electrons emitted in sharply define groups resulting in a beta ray line spectra rather than a continuous spectra.

Gamma radiation is of the type called electromagnetic radiation and covers a range of phenomena from radio waves through light rays to x and gamma rays. This radiation is not associated with matter but represents the propagation of energy through space at the rate of 186,000 miles per second. In contrast to mechanical waves such as sound waves which travel through a material medium such as air or water, electromagnetic waves travel through empty space. Since it is difficult to visualize a wave as traveling without a medium, a hypothetical medium called the ether has been assumed. Regardless of the validity of this assumption, the "Wave" explanation of electromagnetic radiation is useful in explaining known phenomena and in predicting others.

In common with all wave propagation there is a "wave length" which is the distance from crest to crest or trough to trough, or to be more exact, the distance between two points in the medium which are under similar distortion by the wave. There is also a "velocity" of propagation through the medium and a "frequency" with which the waves pass any point in the medium. These quantities are related thus: velocity = frequency x wave length.

Electromagnetic radiation may also be explained as the transmission of bundles of energy called photons. This word is not to be confused with the word proton, they are not the same creature. Certain phenomena connected with electromagnetic radiation can be explained more readily on the basis of bundles of energy or photons. The two viewpoints have been well correlated and each made to serve its specific purpose.

The electromagnetic spectrum refers to a listing of the various wave lengths of electromagnetic radiation. Drawing No. 3.

It can be separated into general divisions depending on the wave length and on the way the radiation interacts with matter. These divisions overlap to a certain extent and the boundaries of the divisions are not sharp. The wave lengths on the chart are expressed in angstrom units, each angstrom unit is equal to 10^{-8} centimeters or .000,000,01 centimeters (cm).

Gamma rays are identical in nature with x-rays of the same wave length. They differ in the manner in which they are produced. Gamma radiation originates in the nucleus of an atom, it doesn't significantly change the mass of the atom, or its number. It is usually thought of as the result of the re-organization of the newly formed nucleus, or at the instant of fission of a nucleus. The energy of the gamma radiation from an isotope is characteristic of that element and doesn't change. In Co^{60} for instance there are two gamma rays, 1.17 and 1.33 M.E.V. This is always the energy of gamma radiation from Cobalt 60.

X-rays are produced whenever fast moving electrons are stopped by matter. They are produced by "bremsstrahlung" effect on the transition of electrons from one orbital energy state to one of a lower energy state.

By now we should know about the origin of the three forms of radiation and some of their properties. The question arises, "What happens when this radiation passes through matter?" We know that a heavy sheet of paper stops alpha particles completely, a couple hundred sheets will stop beta, but gamma radiation is never completely absorbed.

Very briefly alpha radiation ionizes matter giving up energy in small steps, loses speed, finally picks up two electrons, and is thus converted into the element helium.

Beta radiation also interacts by ionization but at a lower rate, and by "bremsstrahlung" effect. Absorption is almost exponential, but at very slow speeds the absorption curve drops to zero. Interactionis much more complicated than alpha due in part to the greater range of energy levels. In any event, both alpha and beta radiation are thus completely absorbed and fully stopped by matter.

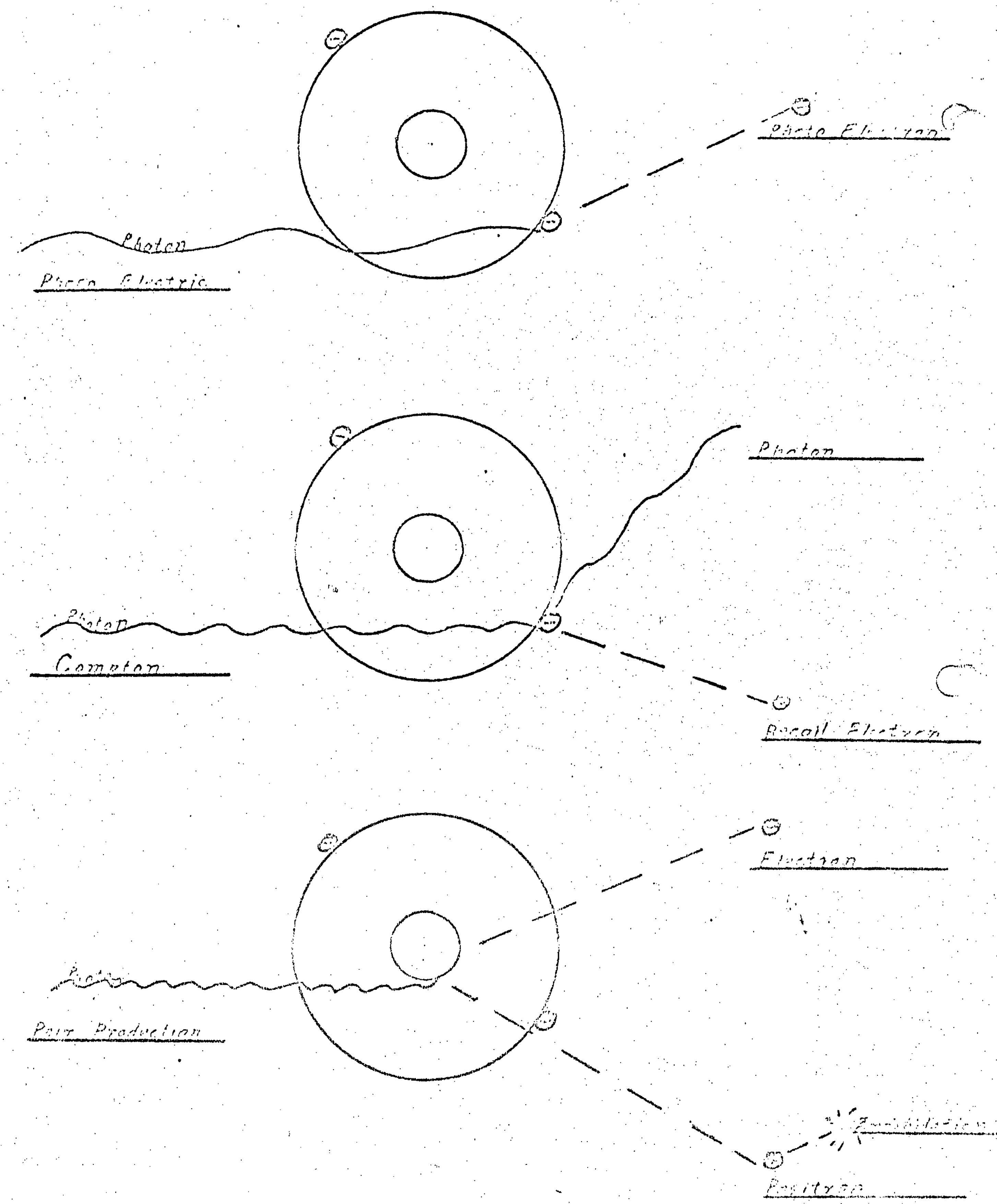
Gamma radiation behaves in a different manner. A single photon passes unaltered by numerous atoms until by chance it interacts with an atom and transfers part or all of its energy to a part of it, usually an electron. The primary beam or ray of radiation is, therefore, not gradually absorbed as charged particles are, but rather it is gradually attenuated or decreased in intensity as photons disappear from it. Complete attenuation is never attained for gamma radiation.

Because gamma radiation is the type we are most concerned with, we shall investigate it a little more extensively.

When low frequency gamma rays pass through the heavier elements the predominate process is the ejection of photo electrons (similar to alpha and beta ionization). For the higher frequencies and lighter elements the Compton Effect occurs.

For the exceedingly high frequencies (very short wave length) electron pair production results.

In the photo electron or ionization effect, a photon of gamma radiation ejects an electron from an atom. The photon is absorbed, and ceases to exist, part of its energy is consumed in the ejection process, the remainder imparts kinetic energy to the photo electron (negative ion). The remainder of the atom (minus one electron) is no longer electrically neutral, it carries a positive charge and is thus a positive ion. The two, positive and negative ions, may be called an ion pair, but do not confuse them with pair production which is another quite different result of gamma radiation interaction with matter.



Radiation
Interaction With Matter

The Compton Effect was discovered by Arthur H. Compton of Washington University in St. Louis. It is the principle means by which x-ray (that is high frequency light waves on the order of 1 M.E.V.) lose their energy. In this interaction gamma or x radiation approaches a free electron (one that is not bound to an atom) or an electron that is loosely held by its atom. As the photon approaches the electron it imparts some of its energy to the electron and deflects it. This electron is called a "recoil electron", the photon of gamma or x radiation then proceeds in a changed direction with reduced energy, and increased wave length. It may suffer several collisions of this kind before it finally escapes from the matter it is passing through, or suffer a collision of the photo electric type and disappear.

Because the photon changes direction with each Compton type collision, it may eventually reach the surface of the matter and be traveling in the opposite direction to that when it entered and thus be scattered backwards.

The recoil electron may collide with atoms ejecting other electrons. If the electrons happen to be removed from the inner orbits of the atoms, upon returning to normal, the energy is radiated as characteristic x-rays.

The third type of interaction between electromagnetic radiation and matter is called pair production. Pair production and its accompliance annihilation radiation is the most recently discovered and most complex of all. It cannot occur in empty space, but requires matter, it usually occurs in the neighborhood of a nucleus. The highest energy photons formed in cosmic rays lose their energy almost completely by this process. As the high energy photon approaches the nucleus it imparts enough energy (it ceases to exist in the process) to a "negative energy state" electron and to raise it to a positive energy state (but still a negative charge) in the process a positive charged electron (positron) is formed. This is called pair production, positron

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and electron. The position cannot exist for more than a millionth or so of a second, it meets an electron almost instantly and the two are annihilated.

In annihilation an amount equal to two electron masses disappears and when mass disappears some form of energy must appear. This energy appears as gamma radiation.

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RADIOGRAPHY ISOTOPE DATA

COBALT 60 (Metallic)	
Energy:	1.17, 1.33 mev
Output:	14,400 mr/hr/curie at 1 foot
Half Life:	5.2 years
Range in Steel:	3/4" - 12"
Source Size:	1 mm x 1 mm - 0.8 curies
	1/16" x 1/16" - 2.5 curies
	1/8" x 1/8" - 15 curies
	.2" x .2" - 60 curies
	1 cm x 2.5 cm - 1800 curies
IRIDIUM 192 (Metallic)	
Energy	300 Kev - 62%; 479 KEV - 29%
	600 KEV - 9%; 375 KEV - Average
Output:	5950 mr/hr/curie at 1 foot
Half Life:	74 days
Range in Steel:	1/4" - 3"
Source Size:	1 mm x 1 mm - 3 curies
	1/16" x 1/16" - 12 curies
	1/8" x 1/8" - 100 curies
CESIUM 137 (Soluble Powder)	
Energy:	.662 mev
Output:	3750 mr/hr/curie at 1 foot
Half Life:	30±3 years
Range in Steel:	1/2" - 5"
Source Size:	1/8" x 1/8" - 1.45 curies
THULIUM 170 (Metallic)	
Energy:	.084 mev; .052 mev
	Bremstrahlung X-Ray to .500 mev
Output:	27 mr/hr/curie at 1 foot
Half Life:	127 days
Range in Steel:	0 - 1/4"
Source Size:	1 mm x 1 mm - 4 curies
	2 mm x 2 mm - 30 curies
	3 mm x 3 mm - 100 curies

Now that we know something about the basic nature of gamma radiation, we will see how they are utilized in industrial radiography.

The energy of gamma rays emitted by an isotope is an indication of its penetrating power and is measured in M.E.V. Penetrating power is important to the radiographer because it establishes limitations governing the thickness of metal which can be successfully radiographed. As the energy or M.E.V. level of radiation increases so does the penetrating power. Co^{60} with a high energy can penetrate much greater steel thickness than the lower energy of Ir^{192} for instance. The Co^{60} with the higher energy will also give a shorter exposure time than Ir^{192} on the same thickness of steel.

The gamma ray energy also effects the quality of radiographs in that it influences the overall contrast. An increase in the energy of radiation causes an associated decrease in radiographic contrast. If two exposures are made of the same object one with low energy (Ir^{192}) and high energy (Co^{60}), there would be an apparent and relative lack of contrast in the film exposed with Co^{60}.

Since the gamma ray energies of radioisotopes differ from one another and since energy directly influences both exposure time and overall contrast, no one isotope can be used universally to cope with all radiographic situations. It should be well understood that this variation of contrast is a matter of the interaction between the radiation and the material being radiographed. The absorption of radiation, and thus the ability to distinguish density or thickness differences gradually decreases for all materials as the energy of radiation increases. Contrast is also a property of a film emulsion. It doesn't vary from one film to another, but from one type to another. Usually as the speed of a film decreases the contrast will increase. Thus HH which is slower than KK will also have more contrast inherent in the emulsion for any given energy level. Contrast is defined as the difference in density produced on a radiographic film by a given charge in specimen thickness. It will be obvious that the greater the difference in density between the image of the flaw and the sound material in a radiograph the easier it will be to detect the flaw. In other words overall contrast is the product of film contrast which remains essentially the same for a given emulsion at all radiation energies, and subject contrast which decreases as radiation energies increase.

As we have seen, radiation is measured in R.H.M., Roentgens per hour at one meter. It is a measure of the amount of radiation emitted and not of the kind of radiation. For example, at the time a new one curie source of Co^{60} is first put into use it emits approximately 1.3 roentgens per hour at one meter. This radiation has an energy of 1.2 M.E.V. At the end of one half life period (5.3 year) the energy will remain at 1.2 M.E.V. but the R.H.M. value would have decreased to .675 or one half of the initial intensity. At the end of another half life the energy would still be 1.2, but the R.H.M. value would have decreased to .3375, which is approximately the same as the R.H.M. value for 1 curie of cesium 137. Consequently, it is possible to have two isotopes yielding the same amount of radiation but not of the same energy. The energy of cesium is .66 M.E.V. To draw an analogy, if the radiation from an isotope is likened to sound, the M.E.V. value corresponds to pitch or tone while the R.H.M. value corresponds to loudness. Intensities can be changed, while energies remain the same. To the radiographer this means that even though an isotope has reached the end of its half life, it can be expected to produce satisfactory radiographs if exposure time is increased to compensate for the loss in intensity. This is true until exposure time becomes so long that definition and contrast is lowered through back scatter.

A comparison of two radiographs, one exposed by gamma radiation from

Cobalt 60 and the other by X radiation in the range from 100 to 400 K.V. would reveal the most obvious difference to be in overall contrast for reasons previously explained. This effect can be termed a lack of overall contrast and can be considered highly detrimental by the radiographer interpreting films exposed through castings of uniform thickness throughout. On the other hand, this same effect can be termed a gain in latitude and consequently an advantage to be exploited by the radiographer when figuring exposures of multi-thickness castings. Latitude is similar to contrast in that itis also a characteristic of a film emulsion. The latitude of a film is closely allied with contrast. It is the density range of a particular film that is useful in making a radiograph. It is not important when radiographing specimens of uniform thickness, but it is a very important consideration in multi-thickness specimens.

Common definition of various words are not accepted by the A. E. C. They are modified or elaborated upon to conform to the more specific requirements of the A. E. C. Therefore, they were not included in the glossary of terms, and require more consideration than a mere definition.

A "Radiographer" is any individual who performs or who, in attendance at the site where the sealed source or sources are being used, personally supervises radiographic operations and who is responsible to the licensee for assuring compliance with the requirements of the regulations of this part (Title 10 Part 30) and the conditions of the license.

A "Radiographers Assistant" is any individual who, under the personal supervision of a radiographer uses radiographic exposure devices, sealed sources or related handling tools, or survey instruments in radiography.

"Occupational dose" includes exposure of an individual to radiation in a restricted area or in the course of employment in which the individuals duties involve exposure to radiations; provided, that "occupational dose" shall

ꟽERICA ATOMIC ENERGY COMMISSION
ington, D.C. 20545

⊃ EMPLOYEES

ROTECTION AGAINST RADIATION

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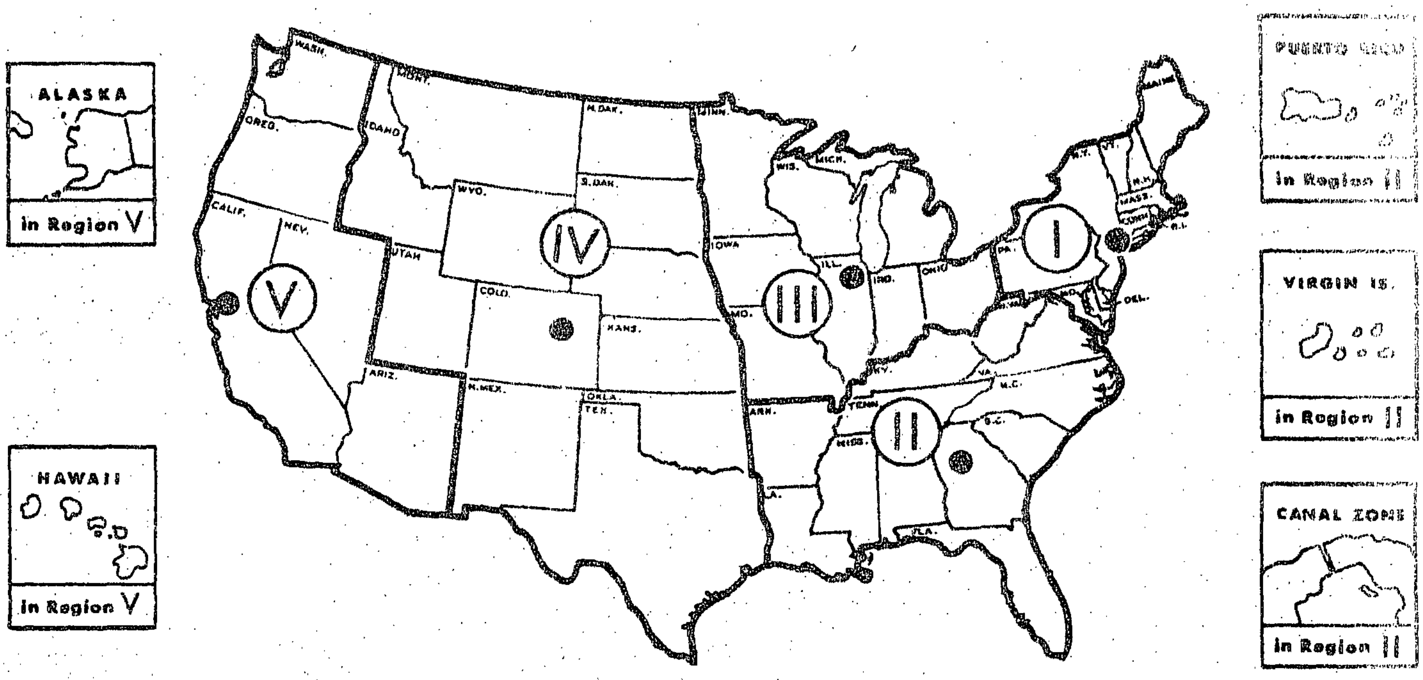

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COMPLIANCE OFFICES

REGION	ADDRESS	TELEPHONE	
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I	Region I, Division of Compliance, USAEC 376 Hudson Street New York, New York 10014	212-989-1000	212-989-1000
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not be deemed to include any exposure of an individual to radiation for the purpose of medical diagnosis or medical therapy of such individual. Therefore, remove your film badge for any medical x-rays you may have during the course of your work day.

"Radiation" itself means any or all of the following: alpha, beta, gamma, x, neutrons, high speed electrons, high speed protons and other atomic particles; but not sound, or radio waves or visible, infrared or ultraviolet light.

"Restricted area" is an area within which, if an individual were continuously present in the area, he could receive a dose in excess of two millinems in any one hour or an area within which, if continuously present the individual could receive a dose in excess of 100 millinems in any seven consecutive days.

A "Radiation area" means any area accessible to personnel, in which there exists radiation originating in whole or in part within licensed material at such levels that a major portion of the body could receive in any one hour, a dose in excess of 5 millinems or in any 5 consecutive days a dose in excess of 100 millinems.

A "High Radiation Area" means any area accessible to personnel in which there exists radiation originating in whole or in part within licensed material at such levels that a major portion of the body could receive in any one hour a dose in excess of 100 millinems.

Within the radiation and high radiation area, A. E. C. approved signs must be posted. Anyone working in these areas and or in a restricted area must have access to A. E. C.-3 which is posted in the betatron building and Co^{60} radiography enclosure, and laboratory office. They must also have access to a copy of the A. E. C. License, regulations and operating procedures, all of which are in the laboratory office, or in the betatron building and Co^{60} radiography enclosure. All of these areas are under the control of the licensee for radiation protection purposes.

BIOLOGICAL RESPONSE TO RADIATION

Dose R	Dose Rate	Exposed Area	Biological Response
0.3	Weekly	Total Body	Probably none
1.5	"	Hands	" "
25	Single Dose	Total Body	Recognizable blood changes
200	" "	" "	Nausea
300	" "	Local	Erythema (100 KV)
300-500	" "	Total Body	LD-50
300-600	" "	Ovaries	Sterilization
400-500	10-50R/day	Total Body	Clinical Recovery
500	Single Dose	Local	Erythema (200 KV)
600-800	" "	Testes	Sterilization
1000	" "	Local	Erythema (radium)

DIAGNOSTIC X-RAY DOSES

Type of Examination	Dose to Examined Part R/exam	Dose to gonads [illegible] exam	
		Male	Female
Chest	.006-.03	0-.01	0.02
Chest (minifilm)	.2-1.25	1	3
Barium Enema	1.25	40-130	20-520
Gall Bladder	1.0	1.8	15.6
Genitourinary	1-2	100	200
Lumbar Spine	1-2	0-24	40-225
Teeth (whole mouth)	3-5	5	1
Fluoroscopy (small field)	7.5 R/minute Minimum	2000 average	2000 average

Average of reported values

Fig XI

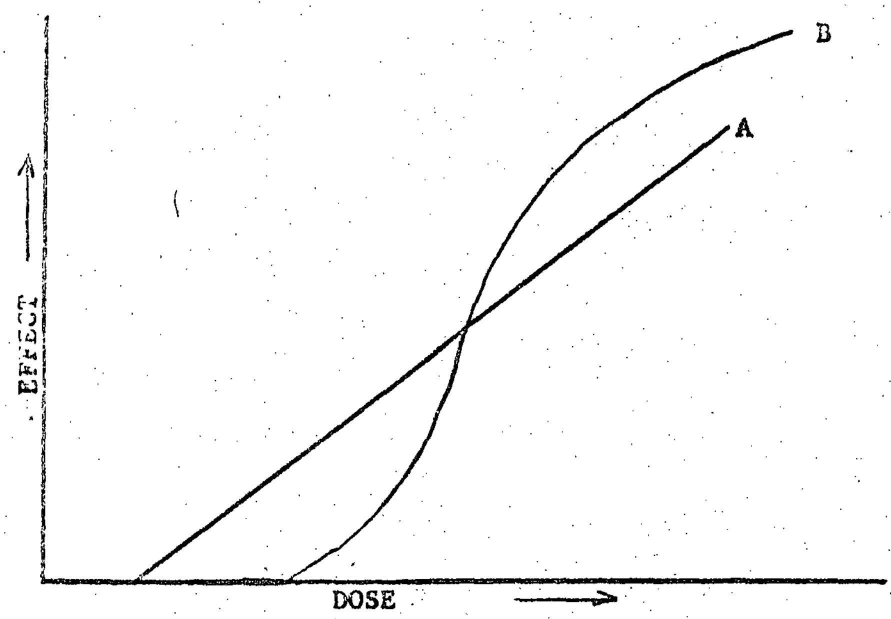
Before we discuss the hazards to health from ionizing radiation it must be noted that for all our scientific advances there is some divergence of opinions regarding tolerance levels and biological effects. Due to the difficulties of extrapolating radiation effect data from flies and small animals to effect on man and to man's longevity some of the information we have is based on theory and opinions. Therefore, there will be some basis for argument. When better biological data are available it is to be anticipated that the question of tolerances will be answered more authoritatively. In the meantime all of us should exercise all reasonable care to maintain exposure as far below the currently acceptable levels as possible.

It is well known that whole body radiation absorbed in the body produces undesirable effects whenever the absorbed energy exceeds certain amounts to which the body has become accustomed in its natural environment, due to background radiation. Investigation has shown that injuries to living cells are in general proportional to the ionization produced in their structure. However, injuries vary for different types of ionization, the intense local ionization produced by alpha particles and protons being more damaging than the less densely localized ions produced by gamma rays.

It is the lethal effect of ionization on individual cells that plays the dominant role in the radiation injuries in the body. If one plots a dose effect graph for various tissues subjected to radiation, there are, in general two forms which the graph may take.

Curve A illustrates the nonthreshold case where, as the dose is increased there is a linear increase in the effect. There is no initial threshold of dose which must be exceeded before an effect is obtained. To recognize a nonthreshold effect, it must be readily observable or measurable after exposure to minimal amounts of radiation. An example would be whole body exposure and its effect on longevity.

Curve B illustrates a threshold effect. Here the effect is not measurable, at least by present methods, until a certain threshold of dose is exceeded. Threshold effects are not linear with dose but assume some form of S curve. The effect of radiation upon the skin and the blood forming organs are examples. Until the dose reaches or surpasses the threshold, the first sign of skin effect, (erythema or abnormal redness of the skin due to capillary congestion) are not seen. The effect upon the blood forming organs is also an example of the threshold effect.



The reversibility of radiation effects is also an important aspect in occupational exposure. By reversibility is meant the return of a tissue to its previously normal state after exposure is discontinued. The reversibility of any specific effect is dependent upon the reparative or regenerative properties of the tissue. Some tissues such as skin, the bone marrow (which contains the blood forming elements), membranous lining of the body cavities or glands and peripheral nerves are endowed with a special type of repair mechanism. Other tissues such as the brain and lens of the eyes have no repair mechanism.

In them, repair is by the formation of a scar, which does not take over the function of the original tissue which it replaces. The effects in such cases are said to be irreversible. In order for an effect to be reversible it must not, of course, produce injury beyond the limits of the normal capacity for regeneration. If it does the effect is permanent and may lead to complete destruction of the tissue.

Both the total dose, and the total time over which it is given, may effect the ability of the regenerative processes to function. If the total dose is excessive, irrespective of the time over which it is administered, regeneration and repair may be impossible. On the other hand, a total dose which will produce reversible effects if given at a rate slow enough to permit regeneration may instead result in irreversible damage to the tissue if given over a shorter period.

The effects of radiation on the human skin gave the first indication of any biologic effect of x-rays and gamma rays. Becquerel, who carried a tube of radium in his vest pocket for demonstration purposes developed a reaction of the underlying skin. X-ray dermatitis was in evidence within a few months after the discovery of x-rays.

The greatest number of radiation injuries have been those to the skin both in x-ray and radium workers. Following the early wave of damage to the skin which came in the first 15 years of x-ray and radium experience, there were more precautions taken to prevent skin damage. The characteristic effect of large doses of gamma radiation upon the skin is the production of a skin erythema. In this respect they are comparable to ultraviolet radiation except that the latent period between exposure and erythema is delayed for several weeks, depending upon the dose. There is a variation on the dose effect ratio to produce erythema with rays of varying quality, in the direction of a larger dose for shorter wave length. As the length of time over which the radiation is administered is increased, the dose required to produce erythema becomes larger. The erythema is the result of a dilation of the fine capillaries and arteriales supplying the skin. The mechanism is thought to be identical with the erythema produced by the ultraviolet ray, such as found in sunshine (suntan and sunburn).

The skin is composed of essentially two layers of tissue, the epidermis which consists of the epithelial cells forming the protective covering of the body and the dermis lying beneath, which consists of the supporting connective tissue for the epidermis, and carries the nutrient vessels, accessory organs and nerve supply. The thickness of the epidermis varies over the body but, in general, ranges from .07 to .2 mm. On the palman surface of the hands and fingers it averages .8 mm and on the soles of the feet 1.4 mm. On the remainder of the body it is considerably thinner, but even a thickness of .1 mm would give protection against alpha and very low energy beta radiation. As cells are lost from this outer layer by normal wear and tear, the underlying growing layer of the epidermis continues to furnish a new supply. We must remember the body is not static, every day cells in the skin, blood, bone and etc. are dying and being replaced by newly manufactured cells. Very low amounts of radiation merely accelerate this replenishment to a small degree. Some radiation physicians are even advocating a theory of increased longevity due to this increased rate of replenishment. However, this remains to be proved.

Beta particles of the average energy associated with out type of work will penetrate well below the skin, and hence there is real potentiality for injury if due caution is not exercised. The dose required to produce erythema is relatively high. As the time over which the dose is administered is lengthened to one or more years a considerable higher total exposure can be tolerated.

More seri[illegible] overexposure signs are a loss of hair; cracking, brittleness, and a loss of normal sensitivity of the skin. This is followed by ulcerations, slow healing of minor cuts and abrasions, and cancerous growths.

The reproductive organs may sustain damage either to the germ plasm or to the cells which carry the germ plasm, ova or sperm. The most sensitive elements in the reproductive organs are the parent cells which eventually give rise to the mature ova or sperm. Other cellular elements in the reproductive organs which are concerned with internal secretion and control the desire for and ability to consummate the sexual act are relatively resistant to radiation. To obtain a permanent sterilization of the female ovary requires 400 - 600 roentgens delivered within the ovary. Sterilization in the man is produced by 800 - 1000r in the testes. There is a threshold of dose which must be exceeded before any effect upon fertility becomes manifest. This possibility of damage to the reproductive organs is the most discussed and probably the most feared hazard in the minds of most nonmedical personnel who work with radiation. The actual incidence of reduced fertility following occupational exposure is not accurately known, but it is not great in comparison with damage to the skin for instance. If the 450 r is accepted for the 50% lethal dose for man and 800 - 1000 r for sterilization, probably even Freud wouldn't worry about it.

Radiation induced mutations have been found to have characteristics which bear on the practical consideration of radiogenetic changes possibly associated with occupational exposure. The most important of these is that there is a linear relationship between dose and increase in mutation rate. There is no threshold effect, the cumulation of exposure is additive. Furthermore, the magnitude of the effect is independent of the wave length and dosage rate of exposure.

Mutations, whether spontaneous or produced by radiation, are about

90% lethal or sublethal. This means that the offspring does not survive the gestation period, or dies shortly thereafter. The lethal mutations are either dominant or recessive. (This has become of paramount concern to the A.E.C. because the increased number of people both male and female working with radiation increases this probability.) By dominant is meant that, for the exposed parent organism, the lethal effect appears in some of the direct offspring. By recessive is meant that the effect might appear only in some succeeding generation of the radiated subject. In man it would appear in the near descendants only should cousins or near relatives intermarry. It has been calculated from the law of genetics that some 5000 years would be required for a mutated gene to meet another mutated gene descended from the original mutation. The danger today lies in the greatly increased number of people working with radiation. The probability of mutated genes meeting is thus somewhat increased. Succeeding generations may bring some abnormalities to light. As yet there is no convincing evidence to indicate that the present generations of radiation workers have produced offspring which differ from those of the general population. This fast becomes more important if we remember that the Manhattan Project started 21 years ago and every year increases our knowledge.

Enough radiation will kill any organism. An overwhelming dose kills instantly, a smaller, but still lethal, dose causes death within hours, days or weeks. Organisms vary widely in their sensitivity to radiation, much more widely than their respective individual cells. In general the more complex the organism, the more vulnerable it is. It takes about 20,000 rem to kill a snail, a few thousand to kill a lizard and a few hundred to kill most mammals.

Furthermore, individuals of the same species react differently. Because of this variation we frequently use as a measure the dose that is lethal to 50% of the individuals exposed, abbreviating it as L.D.-50 (chart).

L.D.-50 figures refer to a single exposure of radiation delivered to the whole body. Much higher doses are tolerated when only a part of the body is exposed. Here the effect will depend on the amount and kind of tissue that is subjected to the radiation, its vulnerability to radiation and its function in the body. A man could absorb a large dose in his hands with virtually no effect on his body as a whole; however, an equal dose to the abdomen could have serious consequences. Moreover, the rate at which radiation is received has a great deal to do with its effect. A much larger quantity can be tolerated if it is divided into small fractions and delivered at intervals. By dividing and spreading the dose, radio-therapists can treat cancerous tissue with thousands of rods without excessive damage to the patient.

What happens to the body of an animal when it receives a dose of radiation in or near the lethal range? The most critically sensitive tissues are the lining of the intestine and the bone marrow and lymphoid tissues that manufacture blood cells. If the dose is big enough the injury is irreversible and death follows in a few days. At smaller but still lethal doses the situation corrects itself somewhat and the most serious problem becomes the loss of blood manufacturing tissue. Death is now delayed for several weeks. It may be due directly to anemia, or to infection following the destruction of white blood cells.

Accompanying these specific effects whether or not they are severe enough to be fatal, is a generalized reactioncalled the radiation syndrome. Its first manifestation is radiation sickness, characterized by nausea and vomiting, usually together with a profound lassitude. Subsequently, the patient may bleed from the gums or nose, and after 10 days or so may lose some hair. The initial sickness does not necessarily depend on damage to specific organs. It follows whenever too much tissue receives too big a dose.

The whole clinical picture suggests a general intoxication.

Is there any treatment for these acute reactions to exposure? So far as the radiation syndrome is concerned we cannot hope to find a specific treatment until we have a clearer picture of its cause. At the present time, we have many loose ends. Most of the knowledge we do have is based on studies of lower animals such as mice and fruit flies, together with fragmentary results of the early radiation workers and the survivors of Hiroshima and Nagasaka. But man is not a mouse or a fruit fly multiplied in size, life span and other biological characteristics. Experiments with them can elucidate principles that may apply to man, but they cannot by themselves supply numbers to put into a human equation. The limits of risk are not completely outlined and research continues on biological effects of ionizing radiation. Because time is a factor for which there is no substitute many of our questions are likely to remain open for generations. Each advance in man's power over the elements has brought with it an element of danger and radiation is no exception.

In the meantime we continue to explore and increase our knowledge. We should proceed cautiously, within the limits deemed advisable by this constantly expanding knowledge.

If one microcurie of radium causes only minor effects in the body and a third causes none that we can observe or detect is it not reasonable to set one tenth microcurie as a limit for occupational exposure. If external radiation 1000 times background produces no apparent damage, is not 50 times background an acceptable risk for radiographers. Perhaps these figures will be revised again as they have in the past, but they seem adequate guideposts for the present.

To maintain gamma ray exposures below the tolerance level prescribed by the A. E. C. three methods are available: (1) Maintain a maximum distance between the source and the radiographer; (2) Maintain any solid or liquid matter between the source and the radiographer. The lead safe itself, to a certain extent projects a cone of lower radiation behind it; (3) Perform the operation of positioning the source as rapidly as possible. Under some circumstances any one of these measures may be adequate, or a situation may develop where only one is possible; however, at all times, if practical, all three should be utilized for maximum protection.

It may seem superfluous to state that the less time an individual remains in a radiation area the better but this is so important, it's the easiest rule to forget, that it cannot be overemphasized. To what extent can we use time as a means of reducing exposure? We might immediately suggest to expose the source as fast as possible and retire to a safe area, but further consideration will produce another method of utilizing time as a means of reducing exposure.

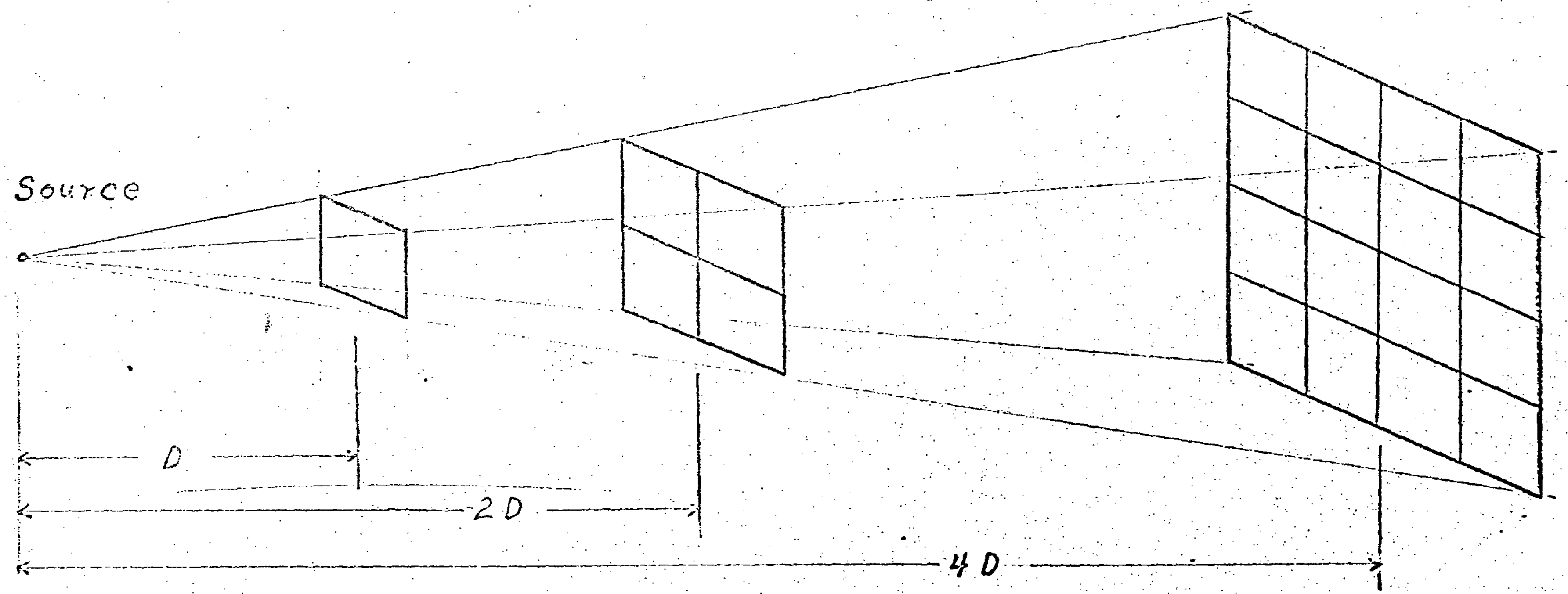
The A. E. C. approved tolerance dose is 1250 mrem per quarter, this figures out to approximately 19 mrems per working day, and 2.4 mrems per hour. If we know the radiation level in an area, as determined in mr per hour by our survey meter, we may calculate the maximum period of time permitted to remain in the area.

$$\frac{\text{Hourly tolerance dose in mrem}}{\text{Gamma radiation level in mr per hour}} = \text{Maximum time permitted in area in hours}$$

Example:

If the radiation level as measured by the survey meter is 12 mr/hour and our hourly tolerance dose is 2.4 mrems, then

$\frac{2.4}{12} = .2$ hrs .2 hr = 12 minutes.



If intensity per square at D is 1
intensity at 2 D is 1/4 and at
4 D is 1/16.

Therefore, a radiographer could remain in this radiation area for 12 minutes of each hour of an 8 hour work day. If it is necessary to enter a radiation area, the time spent within that area must be reduced accordingly as the radiation level increases. The survey meter only indicates the radiation level, the individual must record the time at a radiation level to determine his exposure. The pocket dosimeter intergrades time and radiation level to give exposure dose.

It is difficult for the individual beginning his career in radiography to comprehend the dangers existing from a source that cannot be detected by any of the senses, and the harmful effects of which are only detected hours or days after an overexposure. Radiation dosages from industrial radiographic isotopes can be controlled because the radiation behavior can be calculated and predicted. In industrial radiography at Granite City the source element, size, energy, and characteristics are well known and these rules, tables and formula may not apply to the unknown complex radiation field resulting from an atomic bomb, or reactor catastrophe.

Radiation intensity, as light, is inversely proportioned to the square of the distance from the source. This relationship can be stated algebraically as $\frac{I1}{I2} = \frac{d_2^2}{d_1^2}$.

The radiographer must be intimately familiar with the formula representing the inverse square law. With this formula and a known output for any given quantity of isotope, the radiation intensity at any distance may be calculated. On the chart "Radiography Isotope Data" the output of Co^{60} is given as 14,400 mr/hr/curie at one foot. What is the radiation intensity of 2 curies of Co^{60} at 20 feet from the source $\frac{I1}{I2} = \frac{d_2^2}{d_1^2}$

$I1 = 2 \times 14,400 = 28,800$

$I2 = x$ (unknown)

$d1$ = one foot, $d1^2 = 1$ foot

$d2 = 20$ feet, $d2^2 = 400$ feet

$$\frac{28,800}{x} = \frac{400}{1}$$

$$400\,x = 28,800$$

$$x = 28,800 \div 400$$

$x = 72$ mr per hour at 20 feet

I1 is the intensity at distance d1; I2 is the intensity at distance d2, these values must be correctly matched. Use the chart values for I1 and d1 and compute the other, make certain all figures are expressed in their correct units. By rule of thumb, double the distance and get one fourth the exposure, half the distance and get four times the dose rate. The importance of distance as a means of controlling exposure is thus readily recognized. The chart "Distance VS Curies" illustrates the distance required to produce various radiation levels for different amounts of Co^{60}.

The third method of reducing radiation is called shielding. A shield or protective barrier may consist of dirt, lead, concrete, or water. Its effectiveness depends on the type of radiation and its energy. Co^{60} and Ir^{192} both emit gamma radiation and from the chart "Radiography Isotope Data" the energy of Ir^{192} is less than that of Co^{60}, therefore, less shielding would be required for Ir^{192}, other things being equal.

The shielding effect of these materials is indicated by the term "Half value layer". It indicates the thickness of the shielding material required to reduce the radiation level by a factor of 2. The chart "Concrete Thickness - Inches" gives the reduction factor for the isotopes Co^{60}, CS^{137}, Ir^{192}. An example of its use follows:

A 15" concrete wall will give a reduction factor of 32 for Co^{60} and almost 240 for Ir^{192}. Therefore, if a radiation level on the inside of a 15" concrete wall is 15,000 mr/hr, on the outside it would be 15,000 ÷ 32 or 470 mr/hr for radiation from Co^{60}; and about 15,000 ÷ 240 = 65 mr/hour for Ir^{192}. How does this compare with the half value layer method? From the table we find that 3" of concrete is the amount required to reduce the radiation by one half. A 15" wall contains 15 ÷ 3 = 5 H.V.L. consequently ½ x ½ x ½ x ½ x ½ = 32. 15,000 ÷ 32 = 470 mr/hour. It must be pointed out that various charts and formulas will not always coincide so exactly. Concrete is made up of various component parts and it doesn't always have the same density. For average construction grade concrete with a density of 147 lb/ft^3 the H.V.L. is about 2.75 inches. Other factors such as the actual radiation level, its energy, the thickness of the shield, and the type of interaction all combine to give variation to the chart and graphs. Consequently, do not expect to always find exact duplication of chart and formula data, they should be approximately the same and the figure for concrete of 3 inches for H.V.L. is a safe one.

To find the exact reduction factor for a given shield, a specific isotope, and the same geometry the formula $\frac{I1}{Is}$ applies. I1 is the radiation intensity on the source side of the wall and Is is the intensity on the other side. The chart of reduction factors are the most accurate, because it compensates for some of the previously mentioned variables. For field work it is best to know about both reduction factors and H.V.L., if reduction factors for concrete are not available the 3 inch H.V.L. figure is recommended.

An example of how all three methods may be used to reduce exposure is as follows:

A 10 curie source of Co^{60} is 10 feet from the source side of a 24" thick concrete wall. What is the radiation intensity on the other side of the wall? How long may an individual remain on the other side of the wall and receive less than 2 mr/hour?

1. The inverse square law $\frac{I1}{I2} = \frac{d2^2}{d1^2}$ from "Radiography Isotope Data Chart" 1 curie of Co^{60} = 14,400 mr/hr at one foot.

   I1 = 10 x 14,400 = 144,000 mr/hr

   I2 = x (unknown intensity)

   d2 = 12' (10 + 2) $d2^2$ = 12 x 12 = 144
   (10 feet to wall & 2 feet of wall)

   d1 = 1' (From Data Chart) $d1^2$ = 1 x 1 = 1

   $$\frac{I1}{I2} = \frac{d2^2}{d1^2} \qquad \frac{14,400}{x} = \frac{144}{1}$$

   $$144\ x = 144,000$$

   x = 1000 mr/hr at a distance of 12 feet with no shielding

2. 24" of concrete shielding with 3" as the approximate half value layer

   24 ÷ 3 = 8 H.V.L.

   $$\tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} = \frac{1}{256}$$

   1000 mr/hr ÷ 256 = 3.9 mr/hr at 12 feet with 24" of concrete shielding

3. The level of radiation in an unrestricted area is 2 mr/hr. If the radiation is 3.9 or say 4 mr/hr behind the wall, then no individual would be allowed to remain there longer than that calculated from the time formula.

   Formula

   $$\frac{\text{Hourly tolerance dose in mrem}}{Co^{60}\ \text{gamma radiation in mr/hr}} = \text{maximum time permitted in hours}$$

   $\frac{2}{4}$ = .5 of an hour. .5 x 60 = 30 minutes

Therefore, a man could remain 12 feet from 10 curies of Co^{60} with a shield of 24 inches of concrete for 1/2 hour and receive less than the required

2 mr/hr maximum for an unrestricted area.

These three formulas must be remembered:

1. $\frac{\text{Hourly tolerance dose in mrem}}{Co^{60}\text{ gamma radiation in mr/hr}}$ = maximum time permitted in hours

2. $\frac{X1}{X2} = \frac{d_2^2}{d_1^2}$

3. Theory

$\frac{\text{Theoretical level of radiation without shield}}{\text{*Reduction factor for shielding medium}}$ = radiation level on outside surface of wall

* Reduction factor may be obtained from Graph or calculated from number of H.V.L.

The utilization of the gamma rays of radium in the non-destructive inspection of castings and welds is well established. Its value to foundries and weld shops in raising quality standards and improving methods is an established fact. Many firms would have continued to use radium after the war, but because of its high initial cost, long exposures required with consequent high overhead and withdrawal of government contracts, they were forced to cease using it for radiography. A gamma ray source less costly than radium and available in units of greater specific activity would fill a real need.

With the development of the nuclear reactor large amounts of various isotopes could be produced economically. However, the number that can be used in industrial radiography is severely limited by the criteria which must be met. These are:

1. Energy of the gamma rays
2. Half life of the isotope
3. Specific activity
4. Ease of production
5. Quantity that can be produced

An isotope of Cobalt, Co^{60} and one of Iridium, Ir^{192}, will meet the above criteria. Co^{60} will to a certain extent exceed the capabilities of radium. It is less expensive in initial cost, and its specific activity is 1.55 times that of radium. Its half life is much shorter than that of radium, but at 5.3 years the decay process is slow enough so as not to interfere with exposure times. The intensity of radiation may be recalculated every three months. (A decay curve for Co^{60} is superimposed on the exposure graphs.) Co^{60} is safer to use, radon a decay product of radium, is in gaseous form and is fatal when inhaled. Co^{60} will also give better sensitivity. Sensitivity is the yard stick by which a good radiograph is measured. The Navy Bureau of Ships, A.S.T.M. and other standard setting groups, all demand a sensitivity of 2%. This means that all defects of a magnitude 2% or greater of the thickness of the casting must appear on the radiograph. In a two inch section a defect as small as .040 of an inch will be detected. Sensitivity is measured by a penetrameter. (Fig. 1) Penetrameters are made for each 1/2 inch thickness graduation. They are taped directly onto the castings on the side adjacent to the source and onto each respective thickness. A clear outline of the penetrameter and each hole represents the required 2% sensitivity. For a casting thickness of 2-1/2" or less the small penetrameter is used, over 2-1/2" the larger size is permitted. The thickness of the penetrameter is 2% of the object thickness for which it is intended. (Fig. 1) A sensitivity of 2% is a rather elusive standard, and careful attention to detail must be given at all times. The more important factors effecting sensitivity are:

1. Contrast
2. Film latitude
3. Density
4. Geometry
5. Intensity of radiation

Contrast is the difference in density produced on a radiographic film by a given change in specimen thickness. The greater the contrast between a defect and the surrounding area, the easier it will be to detect the flaw. In radiographs produced by x-rays the contrast is much greater than that produced by Co^{60}; in fact, it is so great that it overcomes the latitude of the film and if the casting thickness gradient is much over one inch a separate exposure must be made for each gradient. This means that in x-raying multi-thickness castings a separate exposure and separate film must be used for each thickness, while with Co^{60} one radiograph will give a complete picture of the casting on one film.

Closely allied to contrast is latitude. Latitude is defined as the density range of a particular film. Latitude and contrast along with emulsion speed and grain are inherent qualities of film and varies with the several types available. In multi-thickness sections the emergent gamma ray intensities

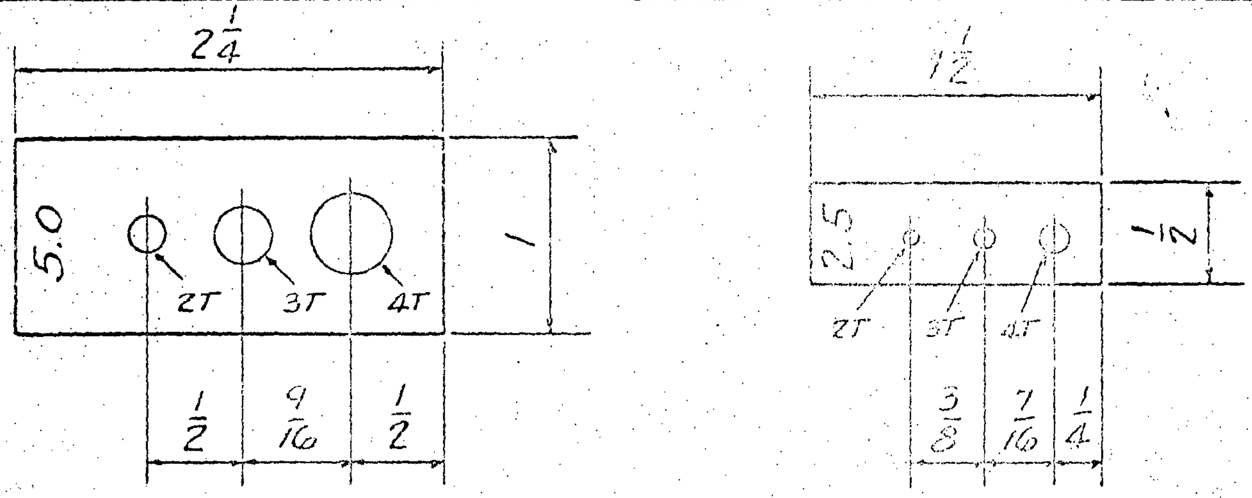


FIGURE 1

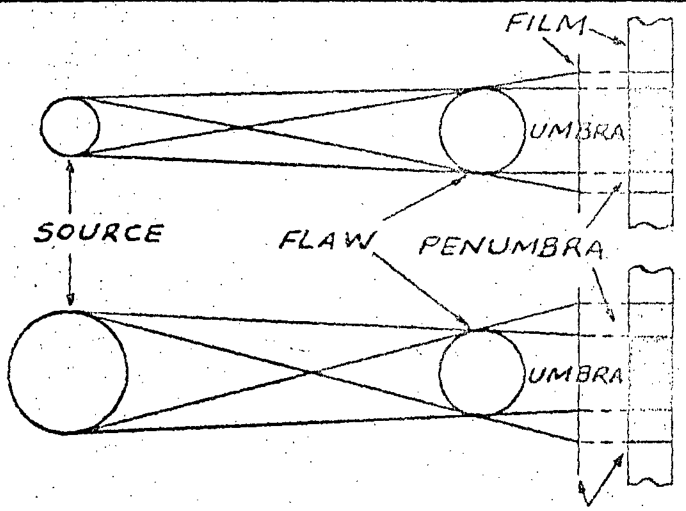


FIGURE 2

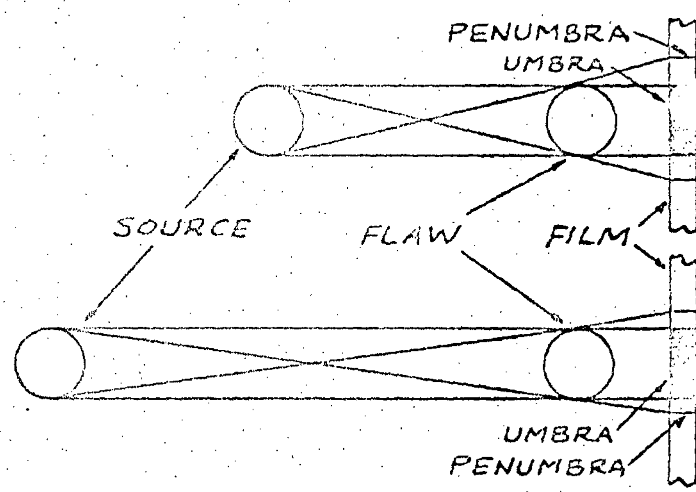


FIGURE 3

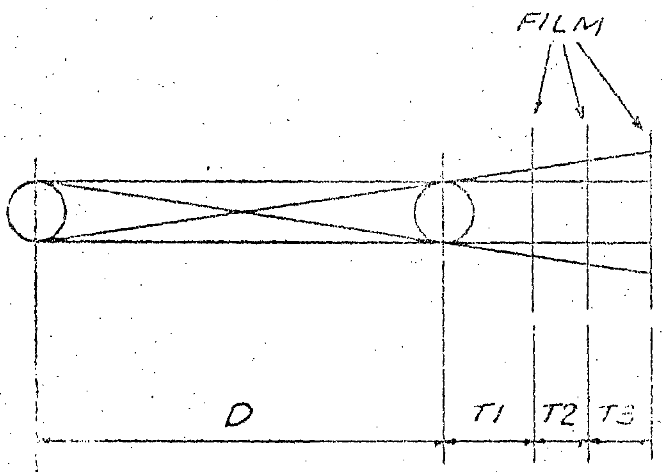


FIGURE 4

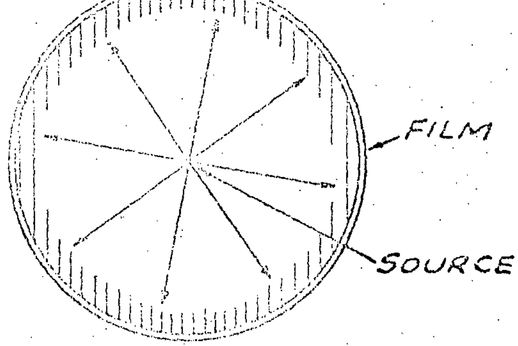


FIGURE 5

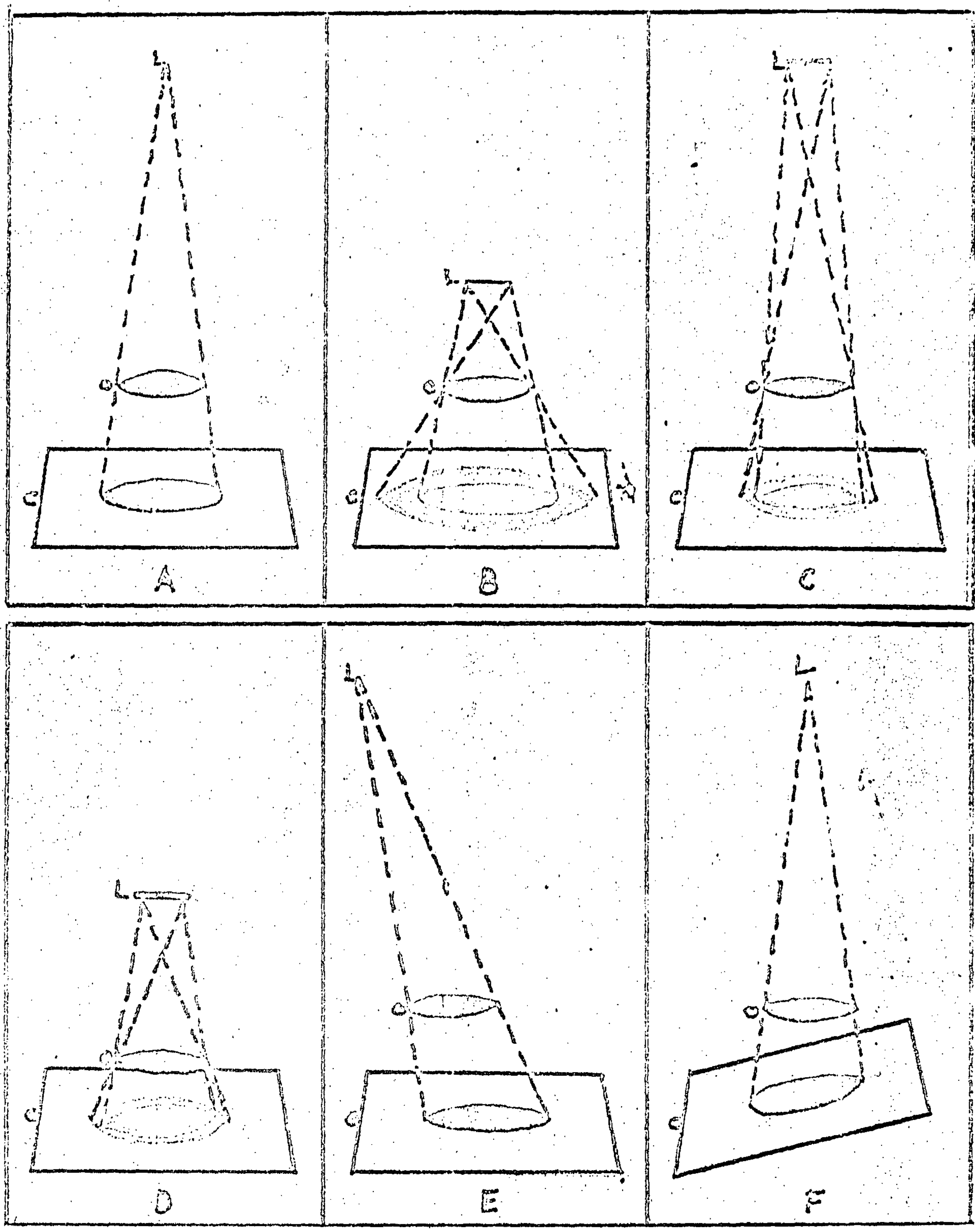


Fig. 8—Illustrating the general geometric principles of shadow formation. In Figures 8A, B, C, and D, enlargement alone takes place. In Figures 8E and F, both enlargement and distortion take place.

will range from a maximum in the region of thinnest section, to a minium at the thickest sections. If the entire subject is to be included on one radiograph and this is desirable, the difference between the maximum and minimum thickness sections must not exceed the latitude of the film.

Density depends on the length of exposure and the intensity of the emergent rays. A density of 2 is usually obtained, this will allow 1/100 of the incident light to pass through the film and is the density commonly seen on medical x-ray film. Most film types have an increase in sensitivity up to a density of five. With this increase in density and a setup that is good geometrically, sensitivity of better than 2% in the 2-1/2" to 6" thickness range is obtained. Below 1-1/4", sensitivity falls off to about 3%. Below 2", Ir^{192} will give 2% or better sensitivity.

A radiograph is to a certain extent a shadow picture, following the common laws of light and shadow formation. This analogy is somewhat untrue due to the fact that the intensity of the emergent rays are affected by the thickness gradients of the casting. The geometry of the setup is of paramount importance. The ideal source size is of course a pin point, this is unobtainable. Figure 2 illustrates the effect of source size on sensitivity. The focal distance, source to film distance, should be as great as time allowed for exposure will permit and Figure 3 illustrates the effect a lengthening of focal distance on sensitivity.

The longer the focal distance and the smaller the source size, the smaller the resultant penumbral region. If the penumbral region is too large, the defect will tend to blend into the normal film density and will be easily overlooked. The penumbra effect is further magnified when it is realized that a defect is seldom a sharply outline circle but rather is irregular in outline. The film holder or cassette should be placed as close as possible to the casting on the opposite side from which the source will be placed. It should be perpendicular to the plane of the central gamma ray and parallel to the plane of the casting. The source should be aligned with the center of the casting, both right and left, and up and down, so as to hold distortion to a uniform minimum. The ratio of the source to defect distance and the defect to film distance should be 10 to 1 with 5 to 1 as an absolute minimum. Figure 4 will illustrate the advantage of the large d-t ratio. The limiting factor is the time allowed to complete the radiograph. The gamma ray intensity follows the inverse square law; therefore, if the focal distance is doubled, exposure time is quadrupled. These variables, focal distance, time and intensity of radiation are complicated further by film type. The choice of the type of film to use depends upon the relative importance placed upon definition contrast and time. Eastman type "A" film is a high contrast fine grained, but slow film, a relative speed of one. Type "K" is a very fast film, relative speed of six, but is low on contrast and has a coarse grain. "No screen" is a medium speed film, relative speed of three, has high contrast and only slightly larger grain than type "A". These three types are representative of other commercial films, Ansco, Dupont, etc.

The film must be handled with extreme care both before and during processing. A heavy finger pressure, a kink, or bending will all produce desensitized areas that will show up on the final radiograph. During processing, care must be exercised so as to avoid dust, uneven development, and drying spots. It is rather futile to figure an optimum focal distance, a good geometrical set up and then through careless processing have so many blemishes on the film that interpretation is difficult if not impossible.

The film emulsion will absorb only a minute percentage of the emergent gamma rays, but will almost completely absorb the secondary radiation or

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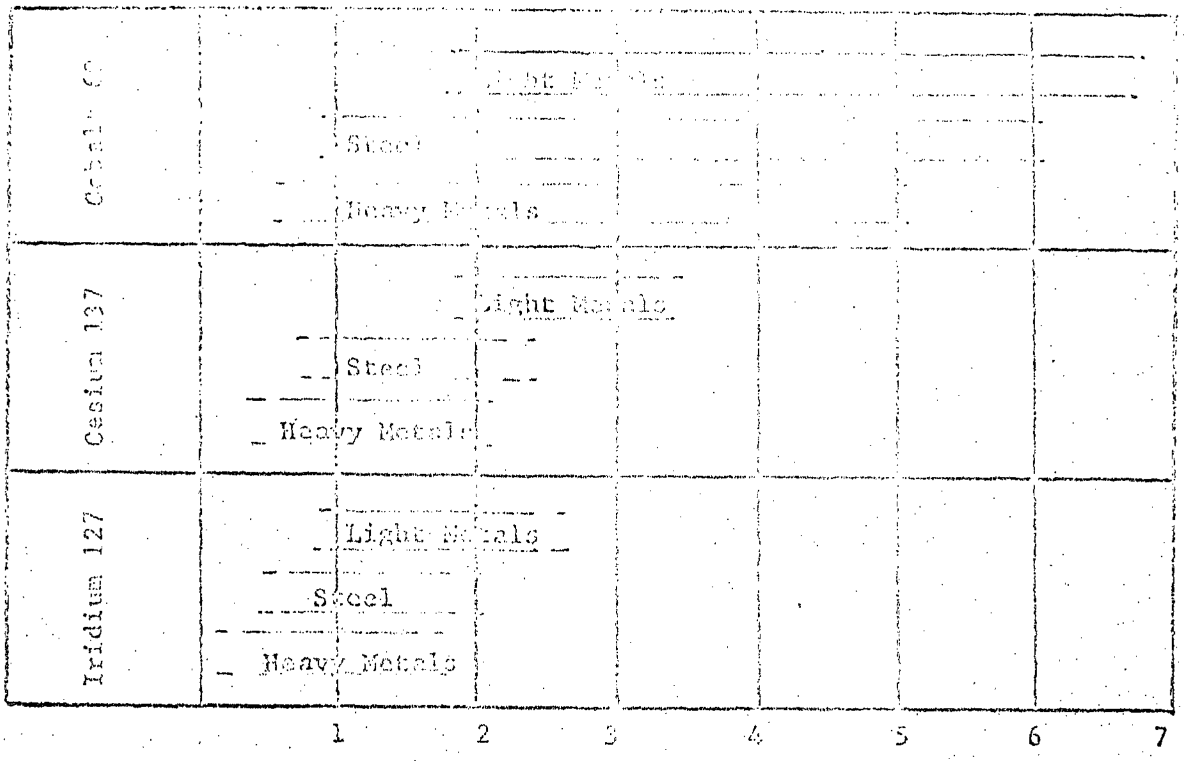
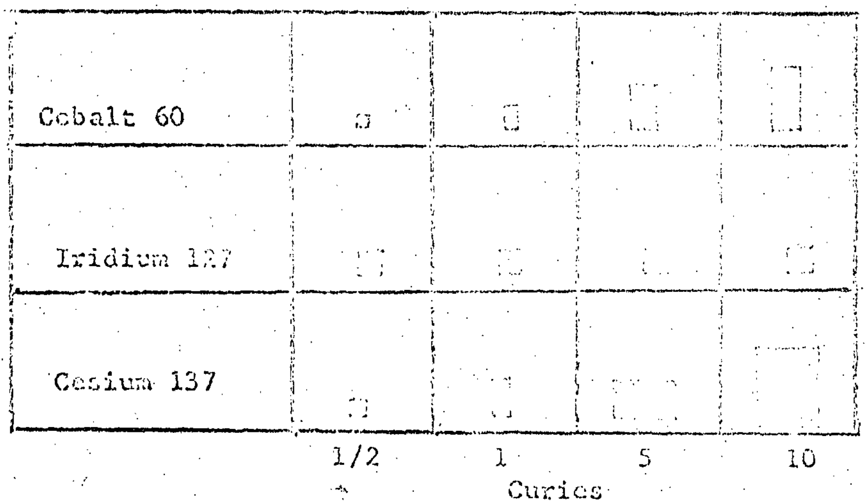
RANGES FOR 2% SENSITIVITY



METAL THICKNESS

SPECIFIC ACTIVITY



Full size cross sections of right cylinders electrons emitted when gamma radiation strikes thin sheets of lead foil. Because of this intensifying action the lead foil is called intensifying screens and vary in thickness from .005 to .015 of an inch. A .010 screen in front of the film and .015 in back will give the highest definition with the least sacrifice of time. The lead screens will cut exposure time from 1/2 to 1/3 of the time required without them. The front screen is the true intensifying screen. The secondary radiation produced in this screen has a very short range; consequently, the film must be placed tightly against the screen. Where actual contact is lost, that section of the finished radiograph will be blurred. The rear screen filters out scattered and bounced back radiation giving better definition to the radiograph. The screens must be maintained free from scratches, dust, or lint because they will absorb some of the radiation, resulting in misleading areas on the radiograph. The lead screens and film are all enclosed in the film holder or cassette.

The strength of radium sources for radiography is stated in milligrams of radium or millicuries; for radium the two units are interchangeable. With Co^{60} these units are not interchangeable. The milligrams of Cobalt present do not measure the strength of the source since the activity per milligram is not a natural constant as it is for radium, but is dependent on the time and intensity of neutron irradiation. The radiation intensity produced by one millicurie of Co^{60} is approximately the same as produced by 1.55 millicurie of radium. The millicurie measures the amount of radioactive isotopes present in a radioactive material and not the intensity.

As the only exposure charts available at the time were calibrated in milligrams of radium, it was a simple matter to convert one millicurie of Co^{60} into 1.55 milligrams radium equivalent. With the preceeding information as a background we can now take up an actual exposure setup.

To complete a successful radiographic exposure, several of the previously mentioned variables must be brought into focus:

1. Thickness of steel
2. Focal distance
3. Type of film
4. Strength of source
5. Exposure factor
6. Time
7. Density desired

The first factors to consider will be the castings and the thickness of the area to be radiographed and the time allotted to complete the exposure. If time is of the essence and the casting is of heavy section a medium fast film such as no screen, a short focal distance and a high intensity source would be mandatory. If on the other hand time isn't as important as the very best in sensitivity, a fine grain film, long focal distance, and small source size would tend to accomplish the desired result.

With the casting thickness measured and the correct type of film loaded, an exposure chart for the respective film used is consulted. This chart is made up on semilogarithmic 2 cycle paper. The subject thickness is the abscissa and exposure factor is the ordinate. Exposure factor is defined as $\frac{A \times B}{C^2} = D$

When A Milligrams radium equivalent
B Exposure time in minutes
C Focal distance in inches
D Exposure factor

On each graph a line is plotted showing the relationship between thickness and exposure factor, corresponding to densities of 3.0, 2.5 and 2.0.

The subject thickness is known, the density is known and by consulting the graph the exposure factor is known.

One of two formulas are then utilized to figure the remaining unknown:

1. $\frac{D \times C^2}{A} \quad B$ 2. $\frac{A \times B}{D} \quad C^2$

When A Milligrams radium equivalent
B Exposure time in minutes
C Focal distance in inches
D Exposure factor

Two techniques may be employed with the above formulas. The first is the internal source technique, wherein the isotope is placed inside the casting and the film, in a flexible cassette is wrapped around the outside. This is especially useful in the radiography of circumferential welding and is illustrated by photograph #1. It is obvious that the focal distance is dictated by the O.D. of the casting; therefore, formula one is solved for exposure time. On this type of exposure the d-t ratio must be remembered. Two per cent sensitivity will not be achieved with a tubing 2" thick with an O.D. of 8" as the probable d-t ratio would be only 4 to 1.

Thicker and more solid shape castings may be exposed over night utilizing technique #2. Gamma radiation flows out from the source in a 360° spherical area and the castings are set up in a circle around the source. To calculate the exposure, use formula #2, time is fixed by the 16 hours between quitting time and arrival the next morning. Focal distance is then calculated. Circles at one foot intervals painted on the floor will help expedite the setting up of the castings. It frequently happens that the castings may not all be of the same thickness, one may be 5 or 6 inches thick, another one inch and several in between, as illustrated in photograph #3. A separate focal distance, formula #2, must be figured for each casting and the exposures made simultaneously. The thickness gradient on a casting may be so great as to overcome the latitude of any individual film type. Type "A" for instance will cover a 2" thickness differential. If a casting thickness range is 3" or as much as 5" one exposure on type "A" film will not be enough, two separate exposures will double the time of handling the casting. If the thickness difference is around 3", two type "A" films are exposed at the same time, both in the same cassette.

After exposure the dense area of the film representing the thinner sections are viewed separately. The area of lesser density, the thick casting areas are then viewed after the second film is superimposed over the first giving an effect of doubling the individual densities. If the thickness gradient is as much as 4" to 5" another technique is employed. One type "A" or slow film, and one type no screen, or fast film, are placed in the same cassette and an exposure time is worked out for each film. The respective exposure times may differ by a few minutes, but an average exposure may be used without noticeably effecting the film density.

After the exposure is over and the film is developed the radiograph should be carefully studied for defects. If a defect is revealed the casting surface should be inspected as not infrequently an inconsequential surface blemish will show up on the film and might be interpreted as an internal defect. If the surface is clean, the questionable area can be chipped out, repaired, and radiographed again. It takes an experienced eye to detect the nature and seriousness of the various defects encountered in steel castings and the decision to scrap or repair is an important one, economically.

FILMS AND SCREENS

Radiographic film differs from ordinary photographic film in several respects. If a photographic film has been given on exposure with ordinary light, it will be found that those grains which have been developed out of the latent image occur mainly near the surface of the emulsion, showing that the light was strongly absorbed by the emulsion. This fact is established by slicing through the film and examining it "edge on" with a microscope. In the case of electromogretic radiation, the rays are absorbed to only a small extent by the emulsion and an examination of the exposed film shows the emulsion. In order to increase the amount of the radiation absorbed by the emulsion, and hence the density of the image, the emulsion is coated on both sides of the film base. Those films intended for use with radiation alone (without intensifying screens) have a thicker emulsion then those to be used with screens. A calcium tungstate intensifying screen consists of crystals which fluoresce with a blue light under the action of gamma or x-ray and, therefore, part of the latent image is due to visible light and part to the action of x-rays, when such a screen is used. Radiographic films have two opposing characteristics, contrast and latitude.

Contrast refers to the amount of change in density of the image due to small change in exposure. The greater the contrast of the film, the smaller the difference in exposure for a given difference in density. Contrast increases with density, generally a darker film has greater contrast.

The greater the latitude the greater will be the difference in exposure required to obtain a given difference in density of the image. Latitude is not of great importance when radiographing specimens of uniform thickness. (weld bottom plates). It is an important consideration in multithickness specimens. In multithickness specimens the emergent gamma ray intensities will range from a maximum in the region of the thinnest section to a minimum at the thickest section. If the whole subject is to be included on one radiograph the difference in exposure between the maximum and mimimum sections must not exceed the usefull exposure range of the film.

The speed of films refers to the exposure required to produce a given density in the image, and usually the grain size in the image will be larger for the faster films. Grain size refers to the size of the individual grains of metallic silver in the image. To obtain fine details, grain size is kept at a minimum but at the expense of speed. Because we use Kodak films a chart of each film's characteristics is included at the end of this chapter.

Radiographic films should always be handled carefully to avoid physical strains such as pressure, creasing, buckling, friction, etc. The normal pressure applied in a cassette to provide good contact is not enough to damage the film, but whenever films are loaded in semi or flexible holders and external clamping or holding devices are used, care should be taken to see that this pressure is uniform. If the film holder bears against a few high spots, such as occur on a welded seam the pressure may be great enough to produce desensitized areas.

If large films are always grasped by the edges and allowed to hang freely marks resulting from contact with fingers which are moist or contaminated with processing chemicals as well as crimp marks will be avoided.

An important precaution to remember is to avoid drawing film rapidly from cartons, exposure holders or cassettes, or hardling it in any manner that would cause friction. Typical film indications caused by improper hardling are illustrated. Note that it is possible to tell if the pressure marks were caused before or after exposure.

Because of the deleterious effect of heat and moisture, all film should be stored in a cool dry place and ordered in such quantities that the supply on hand is renewed frequently. The film should always be rotated. The box bears the expiration date of the film, use the old film first. Do not store in a room near chemicals where there is a possibility of contact with hydrogen sulfide, ammonia, or hydrogen peroxide. Fire hazards are somewhat less than would be presented by an equal amount of newspaper.

Lead screens consist of lead foil placed in direct contact with the surface of the film. To keep the lead foil flat, to prevent wrinkles and to assure good contact with the film, the foil is cemented to a cardboard backing. The front screen is usually .010 to .020 inches thick, and the back screen the same as .005 thicker. The purpose of the screens is to improve the image and intensify the action of the radiation.

The front screen will absorb part of the radiation coming from the object. Both primary radiation (direct from source) and scattered radiation reach this screen. Since the scattered radiation is of less energy and larger wave length then the primary beam, more of it will be absorbed. The reduction of the scattered radiation by this differential action improves the contrast of the image by reducing the general background fog which is produced by the scattered radiation. The lead foil emits photo-electrons due to the mode of interaction between the lead screen and gamma radiation. We have already studied how this comes about. These photo electrons are absorbed by the emulsion on the photographic film more readily than the gamma radiation itself. The front screen therefore results in a shorter exposure time.

The back screen is slightly thicker than the front screen so as to better absorb the back scatter from objects behind the film.

DETECTION & MEASUREMENT OF RADIATION

Radiation from radioisotopes would be of little value if we had no means of detecting or measuring it. Fortunately, a variety of devices are available for this purpose, varying in complexity from simple ionization chambers to highly complex multi-channel analyzer systems. Such detection systems measure the amount, type, and energy of the radiation.

Among the more important radiation detectors are those which react to the ionization produced in them by the incident radiation. This class includes ionization chambers, geiger counters, and cloud chambers. In these detectors ionization is produced by direct interaction of charged particles with the detector or by a reaction of a non-charged particle, such as a neutron or a gamma ray photon, with a constituent of the detector to produce a charged particle which, in turn produces the ionization.

A different class of detectors makes use of the molecular dissociation or excitation produced by radiation in certain substances. This class includes the scintillation counters, photographic emulsions, and various chemical dosimeters. A few of these will be described in more detail.

Ionization chambers measure the quantity of ionizing radiation as a function of the electric charge produced by the ions in a defined volume. Usually they consist of two electrodes mounted in a partially evacuated chamber with a constant potential across the electodes. When such a chamber is exposed to radiation a current will be set-up across the electrodes because the electrons which are knocked off the atoms of gas will be attracted to the positive electrode. The strength of this current is a measure of the intensity of radiation.

Proportional counters are gas filled chambers in which the pulse produced is proportional to the number of ions formed in the gas by the primary ionizing particle.

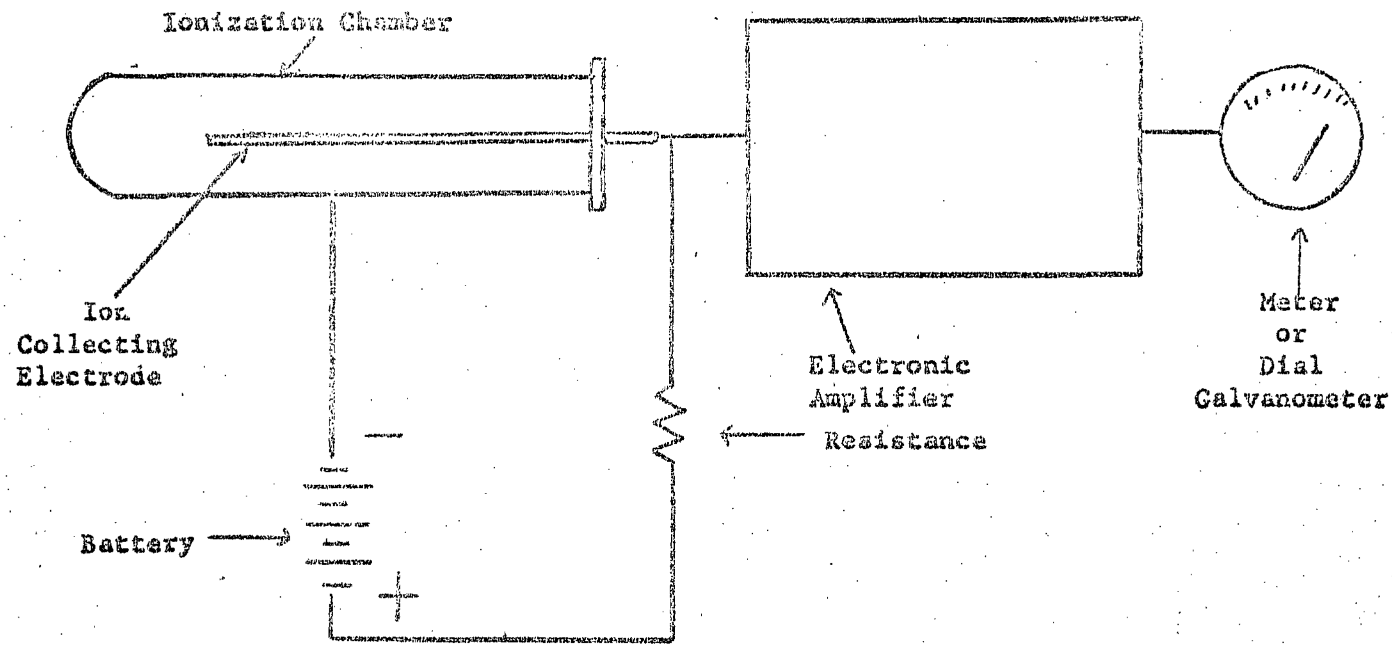
Geiger counters are perhaps the most familiar and widely used radiation detectors. They are highly sensitive gas filled devices which operate at higher voltages than ionization chambers to produce what is known as avalanche ionization. The gas pressure, however, is lower than that in proportional counters. They are very sensitive and somewhat complicated and should only be used by an experienced person. At certain energy levels and in high radiation intensity fields, a condition known as "blocking" occurs and incorrect readings may be made. When the voltage between electrodes is high enough, primary ions produced by the radiation travel to the electrode at a sufficiently high velocity to produce other ions by collision, known as secondary ionization. This process results in an avalanche of ions such that the resulting electric current is independent of the number of primary ions produced in the initial ionizing event.

Cloud chambers are used largely in nuclear research in connection with accelerators to study the interaction of high energy particles. The cloud chamber developed by C. T. R. Wilson is based on the fact that the passage of an ion through a super-saturated atmosphere is rendered visible by the condensation of tiny droplets along the path of travel. The actual path of alpha, beta, and gamma rays become visible to the eye. The chamber is easy to construct and has become a favorite of high school science fairs.

The scintillation counter belongs to the second class. Radiation causes atoms in certain chemicals or phosphors to emit pulses of light when excited by radiation. When such scintillation materials are combined with photomultiplier tubes they form a very valuable and widely used class of radiation detectors.

Photographic film badges are also in the second class. Since photographic film undergoes darkening when exposed to radiation, this effect is used to determine the cumulative radiation dosage by measuring the degree of darkening in a given time of exposure. This type is widely used for personal protection.

Our survey instrument is of the ionization chamber type, and generally follows the basic sketch below.



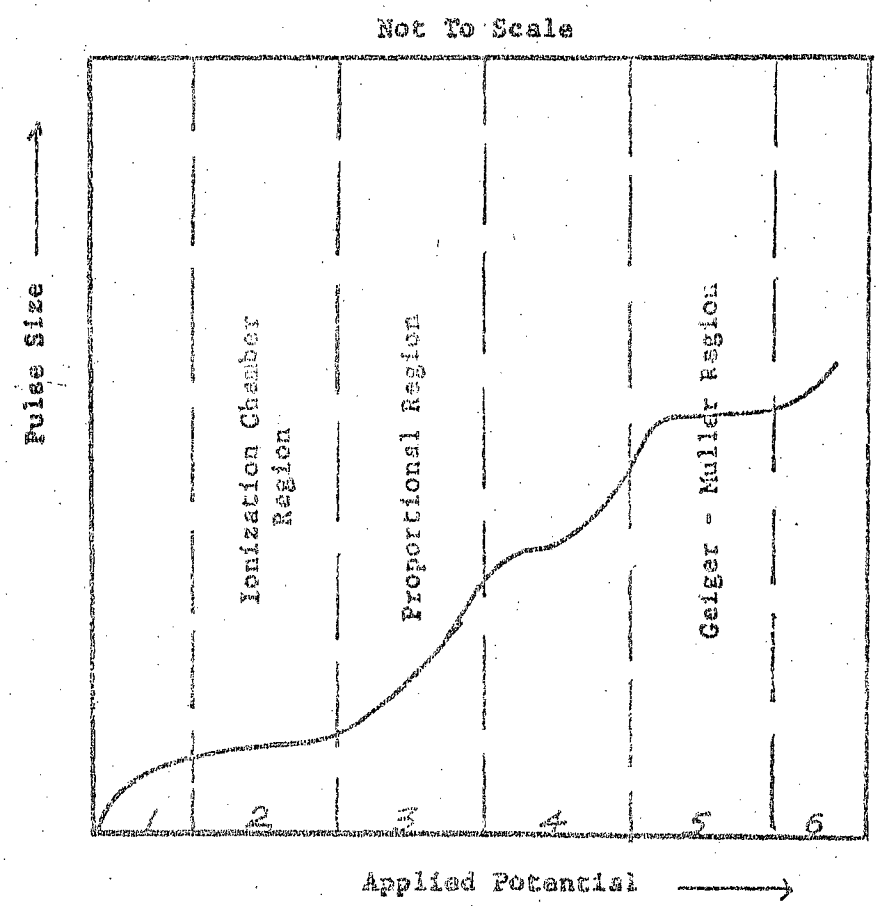
BASIC IONIZATION CHAMBER

The basic ionization chamber was used by Madame Curie in the late 1800's and dates back to the earliest studies of radioactivity.

It consists of a cylindrical chamber, the walls of which serve as one electrode and a thin metal rod, mounted centrally within the tube as the other. The potential across the electrodes is such that no current passes between the electrodes.

Suppose now that a single alpha particle or beta particle, or in fact any ionizing radiation enters the tube. This will cause the positive ions to travel toward the negative electrode, while the negative ions will be attracted toward the positive electrode. As a result charges will collect on the electrodes and an indicating instrument will register a pulse of current. The amount of charge collecting on the electrodes is, of course, ext emely small and the pulse must be amplified by means of an electronic amplifier before the indicating instrument can be made to respond.

If the magnitude of this pulse for various values of the applied voltage, starting at zero and increasing to several thousand volts, is plotted against the corresponding potential, a curve of the shape shown below is obtained.



It is not drawn to scale; its purpose is merely to show the general qualitative nature of the variation of pulse size with the potential applied to the chamber.

It will be noted that this curve is not smooth and that it can be roughly divided into six zones or regions. Three of these regions, 2, 3, and 5 are utilized in various instruments for the measurements of radioactivity. In region 1 the size of the pulse produced by the passage of a single alpha particle increase as a funtion of the applied voltage, but reaches a constant value in region 2, when it becomes independent of the voltage. The reason for this is as follows:

When the applied voltage is small, the ions produced in the tube by the impinging alpha particle move slowly toward the respective electrodes, consequently, there is ample time for many of the oppositely charged species to recombine that is to meet and neutralize each other. The strength of the pulse registered will consequently be less than if all the ion pairs originally formed succeeded in reaching the electrodes. As the potential across the tube is increased, the ions travel faster, so the number of recombinations is diminised, and the pulse size is increased. Ultimately, a point is reached, at the beginning of region 2, when the ions move towards the electrode so rapidly that virtually every ion produced reaches the electrodes. Thus in region 2 the pulse height remains steady even though the voltage is increased. All of the simple ionization chambers operate in this region with voltages that vary roughly between 100 and 300 volts.

It will be noted, however, that in region 3, the pulse height again increases with voltage. This is what is known as the proportional region. For its effective utilization a cylindrical chamber is used which is made the negative electrode. Along the axis of this cylinder is centered a positive wire electrode. When the voltage is high enough the potential gradient near the central wire becomes so large that the electrons produced in the primary ionization of the gas by an alpha or beta particle, are accelerated to high speeds. In region 3 this speed becomes high enough for the electrons to ionize other atoms or molecules in the gas and the electrons so produced may cause further ionization. This condition builds up to the point where the multiplication effect results in an avalanche, thus greatly increasing the pulse height. The total number of ion pairs produced in this way by a single primary ion pair is called the gas amplification factor. It may become as high as 10^6 in region 3. If the voltage is maintained constant in this region the gas amplification factor remains constant and the size of the pulse is proportional to the number of primary ion pairs produced by the incident ionizing particle. For this reason ionization chambers which operate in this region are called proportional counters. The voltages used in operating in this range varies from 500 - 1000 volts and gas is usually a mixture of argon and methane. The argon increases the amplification factor while the methane contributes to more stable operations.

At still higher potentials the character of operation again changes. Region 5 is very useful and is known as the Geiger - Muller region. Conditions in this region make possible the well known Geiger counter. Because of the design of the Geiger counter, in this region the number of pulses become essentially constant regardless of variations in voltage. An important advantage of the Geiger counter is the fact that the gas amplification factor may attain a value so high that the pulses require little external amplification.

The geiger tube is filled with an inert gas such as neon or argon and small amounts of organic or halogen vapor. The avalanche effect is produced giving a pulse of current which activates an electric circuit. The organic or halogen vapor acts to terminate the pulse and restore the tube to its sensitive condition. They do not read true dose ratio unless specially calibrated. They read number of ionizing events without regard to their energy. They can exhibit an effect called "blocking" where a high radiation level may be read as a low one.

PERSONNEL DOSIMETRY

Self reading or indirect reading pocket ion chambers and charging devices are used for individual protection. They are essentially capacitors constructed to discharge in a predictable manner when exposed to ionizing radiation. The charge, placed on the chamber upon proper insertion in the dosemeter charger unit can also leak off indicating an erroneous exposure. They may be accidently dischargød if the tip of the cap, or the finger should rub across the terminal. Dust inside the cap may also result in leakage.

Due to inherrent limitations any off-scale reading must be reported as "greater than full scale", under no conditions may the reading be interpolated, as the actual exposure may be several times full scale reading or only a few per cent high. This is covered in our emergency operating procedure.

These dosimeters are relatively insensitive to beta and alpha particles. Dosimeters are worn only to give the wearer an estimate of his exposure while receiving the dose, in order that he may limit himself to the permissible levels. Disagreement, often as large as tenfold, between dosimeter and film badge measurments is to be expected, the dosimeter usually reading low.

Official records of radiation exposure are the film badge measurments. Badges are constructed with 2 or 3 seperate pieces of film with various types of shielding material in order to ascertain the various types of radiation. Normal accuracy is claimed to be plus or minus 20% for gamma radiation. The badges should be worn clearly visible on the front of the body somewhere between the waist and the neck. This tends to prevent unitentional shielding of parts of the film by pocket carried pencils, etc.

Experience has shown that two points are not fully understood by persons to whom film badges are issued. One is that film badges are not to be abused. This includes delibrate exposure of the badge to radiation while it is not being worn by the person to whom it was issued, the use of the film badge as an experimental detector, and the rearranging of the film in the badge. The other point is that a film badge routinely issued to a person at a particular area should be worn by that person in all areas, so that he maintains a single cumulative record for each period. Do not work in a radiation area withour your badge, always wear only your badge, and in this way maintain your own individual and personal record of your radiation exposure.

INTRODUCTION

The Instruments Division's Model 110A Unitron is designed to safely store or remotely expose an encapsulated source of gamma radiation for Industrial Radiography. A complete unit consists of:

(1) A Model 110A Unitron Head Assembly;

(2) A Flexible Source Tube Assembly;

(3) A Flexible Source Position Indicator Assembly.

The Unitron Head Assembly stores the encapsulated source in a safely locked position and after unlocking, permits free passage of the source into the Source Tube. The Source Tube guides the source to a remote location. The Source Position Indicator Assembly is the mechanical drive system that exposes the source from a retracts it into the head.

A complete unit permits remote radiography of specimens that are 50 feet away from the operator, who may remain behind a shield during the exposure.

Either panoramic shots of several specimens or an internal shot of a single speciment can be obtained by placing the end of the Source Tube Assembly in the proper location before exposing the source.

OPERATION

Attachment of Source Tube Assembly

Remove the aluminum plug from the fitting in the front of the Unitron and thread the source tube coupling into place.

Attachment of Source Position Indicator Assembly

1. Remove the plug threaded into the lock box of the source desired.
2. With the machine locked, pull out the source cable disconnect so that it is exposed approximately 1/4" beyond the lock box.

N. B. Pulling the source cable out with the machine unlocked may result in the source coming out of the head completely and exposing personnel to a radiation hazard.

3. Connect the disconnect on the drive cable with the disconnect on the source cable by bringing them together at right angles.
4. Straighten the drive cable and thread the control cable adapter into the fitting provided on the lock box.

The Unit is not ready for operation.

To set up for operation, the end of the source tube is placed in position where it is desired to have the source appear. The end of the tube may be held in position by tape, test tube clamp, wood blocks, or in any other suitable manner. The source tube should be as straight as possible for ease of operation.

The Source Position Indicator Assembly is then extended to its fullest length in order to keep a minimum number of bends in the control cable and maintain a maximum distance between the operator and the source. It is preferable to have the operator with the control handle behind a personnel shield.

After unlocking the unit with the key provided, the source is exposed by turning the control handle clockwise until the source comes to rest at the end of the source tube. The source position indicator on the handle shows the position of the source in the source tube at all times. No forcing of the handle is necessary.

After the exposure, the source is returned to the head by turning the handle counterclockwise until the source comes to rest in the safe position and the source position indicator reads zero feet. A Survey Meter should always be used to make certain the source is properly shielded. The machine should be locked after each exposure to prevent inadvertent operation and possible overexposure.

Whenever the source tube or source position indicator assembly is disconnected from the head, the plugs provided with the unit should be screwed into the outlet and inlet ends of the head. This will prevent the accumulation of dirt in the head and will also prevent the source from falling out of the head in case of misoperation of the lock.

The pointer on the source position indicator has a tendency to drift slightly over a large number of operations. The pointer is reset to zero with the source in the head and the machine locked. The small screw on the pointer shaft is loosened slightly and the pointer reset at zero feet. The screw is then retightened.

2.0 Operation

Operation of the Cs-40A is extremely simple. The instrument has been calibrated and fully tested before shipment and the operator need only adjust the meter ZERO ADJUST on the top of the instrument case and select the desired meter range to obtain accurate radiation measurement. In addition to the OFF and ZERO positions five ranges on which the meter reading is multiplied by 10,000, 1,000, 100, 10 and 1 are provided giving the instrument the ability to measure fields ranging from 1 mr/hr to 50 r/hr.

To set the CS-40A into operation simply turn the selector switch into the ZERO position. This applies filament voltage to the electrometer tube and power to the time delay circuit. Approximately 1.5 seconds after this voltage has been applied the power oscillator is energized and all required voltages are applied to the instrument. In this position the ZERO ADJUST control should be adjusted for a zero meter reading. It is to be noted that in this position the instrument may be zeroed in a radioactive field of any intensity without effecting the calibration of any of the five ranges. When the meter zeroing has been accomplished turn the selector switch to the X 10,000 position. In taking measurements, it is always desirable to have the selector switch set on the position which gives a near midscale deflection. This switch has been designed so that the first position encountered provides the highest scaling factor.

This prevents the possibility of meter damage which could result from an excessive amount of radiation sending the meter pointer rapidly off scale. After it has been determined that the amount of radioactivity is not sufficient to deflect the needle near midscale, turn the selector switch to lower ranges until the deflection is such that the most accurate reading is obtained. The reading times the scaling factor is the amount of radio-activity present in milliroentgens per hour. A meter sensitivity control is provided at the bottom of the instrument for calibration of the CS-40A. However, this control has been preset and normally will not require readjustment unless components, other than the battery are replaced. Re-calibration should not be attempted unless a known source is available and the proper method known. The screw-driver adjustment on the top of the meter is also preset and should not be moved unless the meter needle indicates something other than zero with the selector switch in the OFF position.

3.0 Calibration

Place the CS-40A in an accurately known gamma radiation field. Turn the selector switch to a range which will provide the meter deflection nearest midscale. Should the instrument require recalibration adjust potentiometer R12 located on the underside of the instrument until the correct reading is obtained. Provide that all range resistors, R1, R2, R3, R4 and R5 and switch S1A are clean and free of moisture, the calibration performed on any range will be valid for the remaining ranges.

FILM BADGE PROCEDURE

1. Film badges shall be worn by all radiography personnel during working hours.

2. Each film badge shall be placed in the film badge storage area at the end of each shift.

3. Due to fluctuation of personnel incoming badges are numbered only. At the beginning of the week take your new badge, use the same number if possible, write your name across the face of the badge. Never use a badge that anyone else has worn.

4. Film badges are to be charged weekly, but if new badges are late, they may be worn a second week also. In this event each man will make a notation of the dates he wore the badge viz June 3 to June 14, 1963. The man mailing the badges to the processing company will make a notation of this on the pocking slip.

5. Control badges remain in the storage area and are not to be worn.

6. All film badges must be kept away from excess heat.

7. When returning badges to the processing company, send all badges, even those not used. Make sure a mans name is on all used badges and write his name, beside the film badge number on the pocking slip.

8. In the event anything goes wrong with the film badge, as if anything happens that these instructions do not cover, call Mr. Robert W. Ripley or William E. Davis, immediately.

UNSATISFACTORY RADIOGRAPHICS

I High Density

A. Overexposure

1. decrease exposure time by one third
2. check calculations of exposure
3. check steel thickness

B. Overdevelopment

1. temperature of developer solution may be too high (over 70°F)
2. wrong time cycle on automatic developer

II Low Density

A. Underexposure

1. increase exposure time by one third to one half
2. check calculations and section thickness

B. Underdevelopment

1. temperature of developer too low (below 65°F)
2. weak and worn out solutions

III Low Contrast

A. Wrong film

1. consult film chart use film of higher contrast

B. Fog

1. film slightly exposed to a light source
2. developer and or fixer, weak or depleted
3. light leaks in dark room
4. prolonged exposure to darkroom "safe light"
5. too high wattage bulb in "safe light"
6. back scatter from radiation, check lead screens, put more empty space behind film while exposure is being made
7. too long developing, hot developer solution
8. old film, always rotate film, the date is always on the bilm box
9. inspection of film before completely fixed
10. do not look at film through a viewer until it is completely fixed

IV Streaks

A. Film hardling and processing

1. failure to agitate film during processing, move films every few seconds in all solutions
2. inspection of film during development
3. use photo flo in final rinse

V Poor Definition

A. Excessive object to film distance

1. place film firmly but gently against the object being radiographed
2. increase source to film distance
3. use smaller source size (physical).

B. Lead Screens

1. dirty and oxidized lead screens
2. paper between lead and film
3. poor contact between lead and film cardboard film holders sometime sag during exposure thus it separates the lead and the film

C. Coarse Grain

1. check film chart, use finer grain films
2. developer too ward

VI Mes

A. White Scum

1. Fixer not completely rinsed oof film

B. Reticulation

1. extreame temperature changes during processing

C. Blisters

1. reaction between alkaline developer and acid fixing bath, will form carbon dioxide gas

GLOSSARY OF TERMS

Absorption - Often used when attenuation is meant refers specifically to processes by which radiation disappears or is transformed.

Alpha Particle - A helium nucleus consiting of 2 protons and 2 neutrons, therefore with a double positive charge. The atomic number of the original isotope emitting the alpha particle is reduced by 2 and its mass number by 4.

Atom - The smallest particle of an element which is capable of entering into a chemical reaction.

Attenuation - The process by which primary quanta or photons are reduced in number on passing through some medium.

Background - Normally refers to radiation due to cosmic rays, radioactive materials in earth as building materials, and the slight radioactive contamination of the instrument materials.

Bremsstrahlung - The production of electromagnetic radiation by the deceleration of a charged particle, usually an electron, while passing through matter. Example is the continuous spectrum from an x-ray tube.

Characteristic radiation - The essentially monochromatic radiation emitted by an atom when an orbital electron is removed or following excitation of the atom. Each element may emit a number of characteristic radiations, each of a constant wave length and different from the characteristic radiations of all other elements.

Collimation - Confining a beam of particles or rays to a defined cross section.

Collision - A close approach of particles or photons during which there is an interchange of energy, momentum, or charge.

Conversion electrons - Are orbital electrons ejected by photoelectric conversion of nuclear gamma rays in the orbital levels of the same atom. They do not arise from the nucleus and therefore do not result in a transmutation. Thus, they are distinguished from nuclear beta particles, although they have the same physical properties.

Curie - Amount of radioactive material defined as the quantity of any radioactive material in which the number of disintegrations per second is 3.7×10^{10}.

X **Decay - (radioactive)** Disintegration of the nucleus of an atom by the spontaneous emission of a particle or a photon.

X **Density - (photographic)** A measure of the degree of darkening of photographic film.

Density - (physical) The weight of a substance per unit volume such as pounds per cubic feet.

Disintegration - Process of spontaneous breakdown of a nucleus of an atom resulting in the emission of a particle or a photon.

Dose - A quantity of radiation.

Electron capture - A mode of radioactive decay in which an orbital electron merges with the nucleus. Process is followed by emission of an electron or photon.

Electron - Volt A unit of energy. The charge in kinetic energy of an electron when it is accelerated through a potential difference of 1 volt.

Energy - The ability to do work. Potential energy is energy due to relative position (elevated weight) or a configuration (coiled spring). Kinetic energy is energy due to motion (a speeding auto or electron).

X **Erythema -** An abnormal redness of the skin caused by a variety of agents including ionizing radiation.

Exposure dose - A measure of the x or gamma radiation at a certain place based upon its ability to produce ionization. The unit is the roentgen.

X **Frequency -** Number of cycles, revolutions, or vibrations completed per unit time.

Gamma Ray - High frequency, short wave length, electromagnetic radiation emitted by the nucleus of an atom. Identical in volume with x-rays of the same wave length.

Genetic - Effect Inheritable changes (mutations) produced by the absorption of ionizing radiations particularly by the gonads. Effects are apparently additive with no recovery.

Geometry - Relative arrangement of source, casting and film.

X **Half-life -** The time required for a radioactive substance to lose one-half of its activity by decay.

Half-value Layer - Amount of shielding material necessary to reduce radiation level by a factor of 2.

Internal Conversion - A mode of radioactive decay in which the gamma rays from excited nuclei cause the ejection of orbital electrons from the atom.

Ion - Atomic particle, atom or chemical radical bearing one or more charges of either sign.

Ionization - The process wherein ions are produced.

Ionizing Radiation - Radiation capable of producing ions by direct or secondary processes; alpha, beta, gamma, neutrons.

Isodose Curve - A curve depicting points of identical radiation dosage in an area.

Isotope - One of several atoms having the same number of protons in their nuclei and hence belonging to the same element but differing in the number of neutrons and therefore in mass number.

K Electron Capture - The process wherein an electron in the K or inner shell of an atom is captured by the nucleus during a nuclear reaction. In the process a characteristic x-ray is emitted.

Kilo - Prefix indicating 1000 as in kilovolt.

Micro - A prefix indicating one millionth.

Milli - A prefix indicating one thousandth.

Monitoring - Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in an area.

Monochromatic radiation - Electromagnetic radiation of a single wave length in which photons are all of the same energy.

Nucleus - The heavy central part of an atom in which most of the mass and the total positive electric charge is concentrated.

X Photon - A discrete unit of energy as waves.

Positron - Particle equal in mass, opposite in charge to the electron.

Primary Radiation - Radiation arising directly from the target of an x-ray tube or from a radioactive source.

Rad - The unit of absorbed dose. It is 100 ergs/g of any material.

Radioactivity - Spontaneous disintegration of an unstable nucleus with emission of a particle or a photon to form a different nucleus.

X Rem - (Roentgen - equivalent - man) A unit of biological dose, it is the amount of energy absorbed in tissue that produces the same biological effect as 1 R of gamma radiation or x-rays. For our purpose 1 R = 1 Rem, this relationship is not true for alpha or beta rays.

X Roentgen - The unit of radiation quantity, which is based on the amount of ionization in air, about 2 billion each of positive and negative ions per cubic centimeter at standard conditions 0-degrees centigrade and 760 mm mercury. It is the amount that produces

Roentgen- (cont'd.)	1.61 x 10^{12} ion pairs in 1 cc or one gram of air, under standard condition. This corresponds to 83.8 ergs of energy per gram of air.
Scattered - Radiation	Radiation whose direction has been altered by an interaction with matter.
Specific - Activity	The total radioactivity of a given isotope per gram, given in curies/gram.
Wave Length -	The distance between any two similar points of two consecutive waves. Expressed in angstrom units or cm.

6. (e) OPERATING AND EMERGENCY PROCEDURES

General Steel Industries, Inc.
Operation Procedure for Use of Cobalt 60 Radiographic Sources

All "Radiographers" (as defined in Title 10, Part 31), 24-MEV Betatron, shall:

1. Read and understand Parts 20 and 31 of Title 10 of the Code of Federal Regulations.

2. Read and become well acquainted with the Instruction Manual for the Budd roll-out camera device and the Radionic Panoramic camera.

3. Read and retain a copy of these Operating Procedures and the attached Emergency Operating Procedures.

4. Receive instructions in the operation of the exposure device and receive actual experience in its operation.

5. Receive instructions and procedures from Mr. H. B. Norris.

6. Receive instructions in health physics, monitoring and personnel monitoring and dosimetry from a physicist from Nuclear Consultants Corporation, or other source including GSI personnel.

Above instructions will include lectures, actual use of exposure devices and survey instruments, and practical problems, utilizing Appendix A, Part 31, Title 10, CFR, as an outline. A copy of this training program is attached as 6(f).

There will be no transportation of sources or exposure devices to any field location, nor in fact, shall they be moved from the special radiographic room within the plant. All records will be maintained by Mr. H. B. Norris or by the division accountant (inventory) in the division accounting department at the same address.

Only "Radiographers" licensed by the AEC and assigned to this department shall have keys to the radiographic room and to the exposure device. Under NO conditions are you to loan or give your key to anyone, regardless of his position within the company without the direct approval of Mr. Norris. If your keys are lost or misplaced, notify Mr. Norris of this at once.

All "Radiographers" must wear film badges whenever working around radiation whether it be x-ray, betatron or the Co 60 sources.

They must also wear the pocket chambers provided when working with the Co 60.

A step-by-step procedure which is to be followed by each shift and each man is tabulated below:

1. Unlock the door to the radiographic room from the outside, enter and immediately lock the door from the inside. This is necessary due to the higher than normal noise level in the plant. A loud siren is located over the door with a push button activator on the outside for use in the event another radiographer must enter the room while it is locked from the inside.

2. Place film holder and any other equipment taken into the room in the small viewing room outside the radiation area (but within the radiographic room). Using the NRD Model CS-40A survey meter, make an entrance survey of each exposure device (Budd Company's Model 110A Unitron Radiographic Camera), making certain no sources are exposed.

3. Make the necessary entries in the Utilization and Survey Log. (See attached sample of log.)

4. Set up exposure film and fix position of source tube. Always place source as near center of room and as far from the walls as is practical. Never place source closer than four feet from the wall unless it is inside the casting. Make certain source tube is firmly fixed in position required, and that any angle in tube is not too sharp to prevent easy operation of source within the tube.

5. Turn on red warning lights. These lights are strategically located on the top of the exposure room walls, and over the outside entrance, so that they may easily be observed by any personnel passing by the area adjacent to the exposure room.

6. Unlock Budd Camera devices.

7. Have castings and camera located so that the control cable may be operated from behind one of the 4 inch thick armor plate steel shields separating the radiographic area from the control area. The control cable shall be maintained behind this shielding at all times. The source may now be exposed utilizing the control cable from behind the armor plate shields. Observe the source position indicator.

8. Make necessary entries in Utilization and Survey Log.

9. "Radiographer" retires to small room outside of radiation area to time and wait for exposure to be completed. At no time should he enter the exposure area (forward of the steel shields) when sources are exposed.

10. After exposure is completed, retract source into source holder with control cable from behind armor plate shielding.

11. Make an operational survey of the entire area, taking special note of source tube and camera device.

12. Lock camera device. This should be done even though a second exposure is to be performed within the next few minutes.

13. Make necessary entries into Utilization and Survey Log. (See attached)

14. Turn off warning light.

15. Steps No. 3 to No. 14, inclusive, may be repeated from two to five times before going to lunch, or between trips to the darkroom and film storage area, or the end of the shift. Darkroom and office are over 500 yards from exposure room.

16. Before leaving the room, whether to go to lunch or darkroom or at the end of the shift, a final survey of source holder and source tube will be made and noted in the log. Be sure to sign the log.

17. Leave exposure room and lock door from the outside. Never leave room, even for a few minutes, without locking from the outside.

18. A final dosimeter reading will be made and recorded at the end of each shift. Film badges as noted above will be worn throughout the eight hour shift, regardless of work being performed.

19. See Emergency Procedure for proper action in case of an emergency. In case of emergency follow those procedures and call Mr. Norris at once. His telephone number shall be known to all radiographers and is always on file in the company guard house which is open 24 hours a day, 7 days a week.

Operating Procedure for Use Of Cobalt 60 Radiographic Source In The Betatron Room

All radiographers must wear film badges and pocket chambers provided whenever working around penetrating radiation, whether it be from the Betatrons or the Co 60 sources.

1. Unlock the door to the Control Room from the outside, enter and immediately lock the door. In the event another radiographer must enter the Control Room while it is locked, he will have to knock on the door.

2. Using the NRD Model CS 40A or the Victoreen Model 592B survey meter, make an entrance survey of exposure device (Radionic Panoramic Camera Model P60-100-A) making certain no source is exposed.

3. Make the necessary entries in the utilization and survey log.

4. Always place the casting as far south as the handling crane will permit, approximately 54' from the north wall. The casting will be as close as is practicable to the east wall. Set up the exposure film and fix the position of the source tube. Make certain the source tube is firmly fixed in the position required and that any angle in the tube is not too sharp to prevent movement of the source within the tube. The Co 60 camera will be set approximately 3' from the east wall and 32' from the north wall. The control crank unit will be inside the control room.

5. Turn on red warning lights. These lights are strategically located at the entrance door to work area and at the double leaf door. Lights may easily be observed by any personnel passing by the area adjacent to the exposure room.

6. Unlock the Radionic's camera device.

7. Have casting and camera located so that control cable may be operated from inside the control room. Observe the source position indicator.

8. Make the necessary entries in utilization and survey log.

9. Radiographer returns to the Control Room outside the radiation area to time and wait for the exposure to be completed. At no time should he enter the exposure area (forward of the 10'0" thick sand filled wall) when the source is exposed.

Operating Procedure for Use of Cobalt 60 Radiographic Source in the Betatron Room (Continued)

10. After the exposure is completed, retract the source into the camera by means of the control cable from inside the control room.

11. Make an operational survey of the entire area, taking special note of source tube and camera device.

12. Lock camera device. This should be done even though a second exposure is to be performed within the next few minutes.

13. Make necessary entries in the utilization and survey log. (See attached)

14. Turn off warning lights.

15. Steps No. 3 to No. 14 inclusive may be repeated several times before going to lunch or the end of the shift. Darkroom and offices are located in the processing area behind the 10' 0" thick sand filled wall.

16. Before leaving the room, whether to go to lunch or darkroom or at the end of the shift, a final survey of source holder and source tube will be made and noted in the log. Be sure to sign the log.

17. Leave exposure room and lock door from the outside. Never leave room, even for a few minutes, without locking from the outside.

18. A final dosimeter reading will be made and recorded at the end of each shift. Film badges as noted above will be worn throughout the eight hour shift, regardless of work being performed.

19. See Emergency Procedure for proper action in case of an emergency. In case of emergency, follow those procedures and call Mr. H. B. Norris at once. His telephone number shall be known to all radiographers, and is always on file in the company guard house, which is open 24 hours a day, 7 days a week.

EMERGENCY OPERATING PROCEDURES

A telephone is located in the small room protected from the radiation area but within the locked exposure room. Any deviation from normal operating procedure may be reported to the supervisor in charge of radiography without the necessity of the radiographer leaving the locked exposure room. All men handling the source will be radiographers within the definition of Part 31, Paragraph 31.3.

<u>EMERGENCY NO. 1</u> SOURCE CANNOT BE RETRACTED INTO THE SOURCE HOLDER OR THE SURVEY INDICATES THAT IT IS NOT WITHIN THE HOLDER WHEN IT SHOULD BE. THE RADIOGRAPHER ON DUTY SHALL:

1. The warning lights will be on in conformance with operating procedure. If the emergency happens at any other time, turn on warning lights.
2. Call H. B. Norris, by auto call or telephone.
3. Unlock door, leave radiation room, and lock door from the outside.
4. Using NRD Model CS 40A survey meter, survey area immediately surrounding radiographic area, and post any area of greater than 5 mr/hr.
5. Maintain vigilance at doorway until Mr. Norris arrives.

<u>THE RADIATION SAFETY OFFICER SHALL</u>

1. Obtain full story, evaluate, rectify if possible.
2. If necessary, call Nuclear Consultants Corporation or the Budd Company. Exposure room will remain locked and all warning lights will remain on until area is safe. Radiographer will maintain personnel vigilance at exposure room door if gravity of situation warrants.
3. Record will be made of the incident.
4. AEC will be notified, if necessary, in compliance with Title 10, Part 20, Paragraph 20.403.

EMERGENCY NO. 2 POCKET DOSIMETER READS OFF SCALE

1. Do not extrapolate.

2. Recharge dosimeter, check it after 15 minutes, repeat this step. If it reads off scale both times, it is probably faulty.

3. Develop casting exposure films, see if they have the correct density with no distortion. Any misalignment of source or source tube that could result in overexposure would not give a satisfactory radiograph.

4. Check survey instrument. If survey instrument and radiographs prove to be all right and dosimeter indicates a faulty discharge, assume dosimeter to be faulty. Use spare dosimeter.

5. Call H. B. Norris and notify him of these results for his evaluation before making any other exposures.

6. If above indicates that the apparent overexposure may have actually occurred, send film badge in for processing with request for an immediate reply by telephone.

7. If film badge report substantiates dosimeter reading, the radiographer will be sent to the corporation doctor with a full report.

8. AEC will be notified in conformance with Title 10, Part 30, Paragraph 20.403.