Industrial Radiography Testing & Technique

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Abstract: The use of Industrial Radiography for examining the quality of Weld joints is very popular worldwide. In India, many welding activities like construction and laying the huge pipelines for gas and water transportation and distribution as well construction of storage tanks are performed. The objects are working under high pressure and therefore, it is important to produce the weld beads with high quality. Industrial radiography uses ionizing radiation to view objects in a way that cannot be seen otherwise. The method has grown out of engineering, and is a major element of non-destructive testing (NDT) to inspect materials for hidden flaws. The radiation caused by these facilities is very dangerous however, with the use of new technologies and proper protection, risks of injury and death associated with radiation can be greatly reduced.

Keywords: *Radiography*, Safety, PIPE, Procedure, Camera, Lock, NDT, TAEC, SFD Ionizing Radiation, Radiographic Inspection, Radiation Devices Register, Safety, Weld defects.

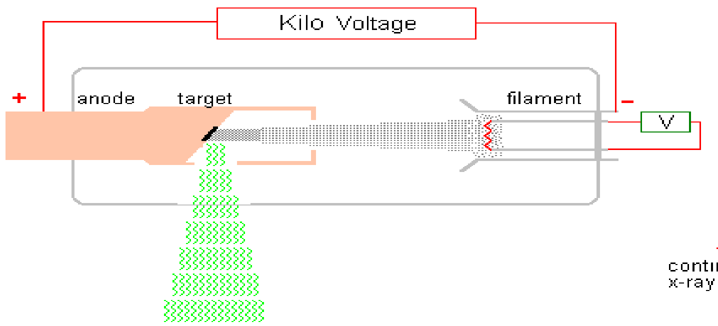
INTRODUCTION:

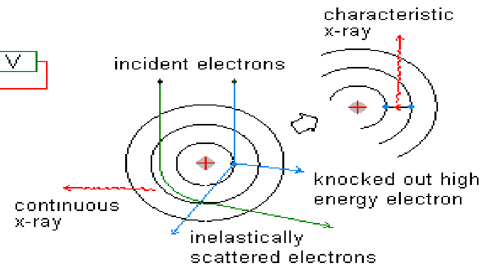
Radiography is non-destructive testing (NDT) method to find out the internal discontinuities present in a component or assembly. It is based on differential absorption of penetrating radiation by the part being inspected.

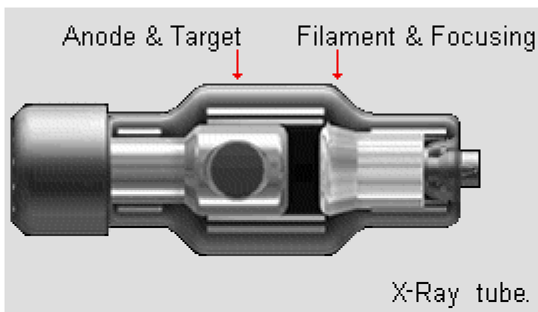
The basic principle for the detection of anomalies using radiographic testing method is the difference in radiation absorption coefficients properties exhibits by different materials. The images are captured in a recording medium. The recording medium used may be X-ray film, phosphorous imaging plates, diodes etc. Industrial X-ray films are the common recording medium used for these applications' the last five decades, non-destructive testing (NDT) methods have gone from being a simple laboratory curiosity to an essential tool in industry [1]. The inspection of welds is a very important task for assuring safety and reliability in several industrial sectors, e.g., ship and aircraft industry. For this purpose NDT techniques have been employed to test a material for surface or internal flaws without interfering in any way with its suitability for service. Such methods are the acoustic emission, magnetic particle inspection, eddy current, ultrasonic testing, thermal inspection and several others. These techniques are based on the observation that weld defects cause some sort of discontinuity to the test signal, which allows for recognition. However, each method is appropriate only for specific types of defects. We are therefore in a situation, possibly unique, where we see radiography from the perspectives of both service provider and customer.

The first goal of this paper is to discuss who should be the appropriate person to take prime responsibility for safety when radiography is performed. The second is to briefly re-visit an event where a source had to be retrieved from a difficult location. Some lessons learnt at that time have been published more importantly; the experience strongly suggests that some developments in gamma camera design are wrong.

Radiation is such a powerful and dangerous divine rays that humans cannot see by themselves, coming in contact with it can cause serious illness or death to a person. Dr. HARDEV







Industrial X Ray sources : X - rays are electrically generated radiation and the energy of the emitted radiation can be controlled. X rays are produced when electrons traveling at high speed looses energy by collision with matter or change of direction.

The usual type of x ray tube is a glass, ceramic or metal ceramic housing, where the spacing of electrodes and the degree of vacuum is such that no flow of electrical charge between the cathode and anode is possible until the filament is heated. The filament when heated with a suitable low voltage Controlled supply, emits electrons and thus forms the cathode or negative Electrode. The positive electrode is a solid block of copper with a tunnel at One end and a piece of tungsten embedded on the inside face of the tunnel End. The tungsten is the target or focal spot. A controlled high voltage is Applied between these electrodes, drives the electrons rapidly towards the Target. The sudden stopping of these rapidly moving electrons in the surface of the tungsten target results in generation of x rays. Much of the energy Appears in the form of heat and intense heat is produced on the target. Many of the electrons knock out orbital electrons from the target atoms while others get deflected by the positive charge of the nucleus. These actions generate characteristics and continuous x-rays respectively. The continuous spectrum generates sufficient energy to penetrate materials and form the x-ray image. The machine is generally used for a shorter ‘on‘ time followed by sufficient ‘off ’ time for air cooling. The machine cannot be operated continuously without efficient cooling arrangement and is generally achieved by water circulation. The generated x rays have all the energies within the emitted spectrum. The lower energies contribute greatly towards image contrast and sensitivity and the radiograph is superior when compared to gamma rays. Sensitivity of 1% can be achieved in most cases.

The intensity of radiation [mR / min] mainly depends on the number of electrons emitted by the heated filament and is controlled by the current passing through it. The energy of radiation [keV] depends on the voltage applied between the anode and the cathode and is selected considering the material, its thickness and radiographic sensitivity requirements.

Machines most commonly used are 160 to 400 kV [Tank type] with 4 to 8 mA beam current within the portable range and 2 to 6 meV and more [Betarons and Linear accelerators] in the high energy range. Portable machines generate either directional or panoramic beam. Most of the machines are not suitable for working at heights and with all types of exposure setups. Linear Accelerators and Betterton's uses different tube arrangements and methods of electron acceleration. The heat generation is also less and the JME 6 mev Betterton can operate without external cooling. The high energy machines are heavy, very costly and the energy of radiation cannot be adjusted continuously.

If X-ray is less, then gamma is more, if it is beneficial, then if it is used incorrectly, it is more harmful. DR. HARDEV

3. Procedure for radiography performed in the refinery by contractors

3.1. Purpose

To state requirements for contractors performing radiography in the refinery and for all supervisors or engineers who utilize their services.

3.2.Scope

This procedure applies to all radiography performed by contractors in the refinery, and gives guidance for radiography performed 'in house' and for other use of ionizing radiation performed 'in house' or by contractors.

3.3. Definitions

Contract Radiographer: A radiographer not working under the direct supervision of the head of Inspection Department.

Radiation is such a powerful and dangerous divine rays that humans cannot see by themselves, coming in contact with it can cause serious illness or death to a person. Dr. HARDEV

3.4 Supervisor: The person in direct control of the job of which radiography is a part. This would typically be a Refinery or Contract engineer, a refinery maintenance supervisor or a mechanical contractor's supervisor.

3.5. Procedure

a. The Supervisor has the prime responsibility for the safety of the work,. He is to ensure that the Contract Radiographer is individually approved for work on the Refinery has received site induction and other site training appropriate for the work and has been issued with gate and vehicle entry passes as applicable. He is also responsible for ensuring the Contract Radiographer is familiar with the scope of work and that a radiography permit has been submitted for approval, duly signed by a Refinery Radiation Safety Officer.

b. The Supervisor shall inspect the site with the Contract Radiographer to establish the means of roping off the proposed radiation area, and will ensure that the Contract Radiographer is aware of all potential means of circumventing the barrier, for example by climbing ladders outside the barrier that provide access to areas within the barrier or by entry to ducting or other equipment nearby. The Supervisor and Contract Radiographer shall ensure that all practicable measures are taken to prevent this. Where required the Supervisor shall provide manpower to assist in clearing the site.

It is imperative that the Supervisor ensures all personnel are cleared from the site, not just those working directly for him.

a. The radiographer shall not expose his source until he has ascertained that the area is clear of personnel.

b. It is strongly recommended that the manner and timing of radiography is planned before a major TAR or revamp, with site inspections to ensure radiography sites are selected as far as possible in locations that minimize risk of accidental exposure. It is further recommended that radiography is performed outside normal working hours,

c. *but this in no way diminishes the responsibility for ensuring the area is clear of personnel.*

d. Under no circumstances is work to commence, requiring the use of a radioactive source or x-ray equipment, without an authorized radiography permit. The Contract Radiographer is responsible for collecting the permit from Operations and advising Operations when work is completed. He is also responsible for obtaining the Supervisor's authorization of gate passes to remove his equipment from the Refinery when the job is complete.

e. The Radiography Permit is to be signed by the Operations Shift Manager, to indicate that Operations are aware that radiography is being conducted on site. A Refinery Radiation Safety Officer is also required to sign the permit where a Contract Radiographer is to perform the work.

f. The Supervisor is to ensure that Contract Radiographers who have not been approved to perform radiography at the Refinery report to a Refinery Radiation Safety Officer before starting work.

g. The contractor shall adhere strictly with all legal requirements, specific precautions set out by the Radiography Permit and his own company's procedures (approved by the Queensland Division of Radiation Health), in that order of precedence. Any contradiction in these requirements shall be resolved with the Refinery Radiation Safety Officer before work commences.

When updated a copy of this procedure is to be sent to contractors used on site, and to inspection companies who provide contract radiographers.

4.*INDUSTRIAL RADIOGRAPHY INFORMATION NOTE (Draft) Purpose of this document:*

To provide you, our client, with information you need if you are to ensure that radiography can be conducted on your site with minimum disruption to work;

To ensure that we have the information we need from you to assure you that the work will be conducted efficiently and safely.

The information given here is necessarily very general. It is strongly advised that details of the work are discussed with
us well in advance. It is emphasized that while the radiographer is responsible for the safe use of his equipment, *you have overall responsibility for safety.*

4.1 What is radiography, and why is safety an issue?

Radiography involves the use of a beam of radiation to create an image which shows the internal structure of an otherwise opaque object. The radiation can damage living tissue and precautions must be taken to ensure no-one is damaged by the process.

4.2 How can you help?

We need to know what components and what parts of each component are to be inspected by radiography, the material it is made of and its thickness, and what acceptance standard applies. If radiography is not for weld inspection we need to discuss details of what you want to achieve.

The radiographer will need to have sufficient access to both sides of the components.

An area around the work site will need to be vacated of all personnel. This area may be several tens of meters across depending on the situation. You should plan your work for the day so that this can occur with minimum disruption.

Where radiography is to be performed within several tens of meters of a wall (or ceiling or floor with occupiable space above or below, or any obstruction to view), the radiographer must be assured that there is no possibility of anyone being behind it while the radiation beam is active. Concrete blocks and other building materials offer very little shielding from the radiation used. Particular care must be taken where a wall is on a property alignment, and in such an instance it may be necessary to make suitable arrangements with your neighbors in advance. Where the adjacent property is public land, or where public land is within a few tens of meters of the job, it may be necessary to make arrangements with local authorities.

Each situation will be different, and in many instances there may be a way around a particular problem. For example the radiation beam can often be mostly directed away from a sensitive area, but this will depend on the geometry, size and mobility of the component and the nature of the inspection.

5. Single Wall Exposure Techniques [welds] :

This is the most used and recommended technique for radiographic recording where two opposite sides of a solid test object are accessible.

6. Exposure preparations :

Radiation source / energy : is selected based on test material absorption, thickness to be examined and type of the film. Optimum contrast with minimum 2% recording sensitivity are the requirements.

Visual examination : Visually detected surface imperfections which will produce images on the radiograph shall be rectified before shooting.
Segment marking : The weld length is divided into suitable number of segments A –B / 0 –1 etc and marked such that the marks remain on the object till the weld is accepted. Identical segment marking is necessary on the source side and the film side of the object for accurately positioning the film and other accessories around the weld.
Film Size : shall be at least 2” more than the length of the segment to be examined. Width shall be sufficient to record the weld, all markers and the complete pentameter outline.
SFD : Minimum SFD is to be calculated using the SFD equation. Thumb rule, 10 times the object thickness and 1.1 X length of the film, which is greater. Recommended minimum SFD is 15”.
Location Markers : shall be placed on the marks near the weld, in sequence 1, 2, 3 / A, B, C etc on the source side of the object, unless a predetermined overlapping length between successive films is used.
Identification Markers : as required, shall appear in each film, placed near the weld.
Pentameter : 2 % of the thickness being examined. Can also be selected from the table of the applicable specifications / procedures. Weld reinforcement to be included in pentameter selection. Pentameter must be attached to the source side of the object.
Wire type : to be fixed near the location marker and across the weld, the thinnest wire in the set towards the location marker.
Hole type : to be fixed near the location marker, 3.2 mm away and parallel to the weld, 2T hole towards the location marker.
Shim : used to simulate the weld reinforcements, to be placed under the hole type pentameter only, thickness of the shim should be nearly equal to the total weld reinforcement. Shim may be single or staked thin sheets and must be larger than the size of the pentameter.
Set up : Location markers are fixed on the source side marks and radiograph identification markers are fixed near the weld using adhesive tapes. The applicable pentameter is fixed on the source side and near a location marker also with tapes. The film is then attached in close contact with the surface, opposite to the source side using magnets or adhesive tapes.
Using a magnetic supporting stand, the exposure point of the source guide tube is secured exactly at the central axis of the segment under examination and at a distance equal to the SFD. The object should be positioned such that the recording plane of the film is perpendicular to the imaging radiation beam. The film is then irradiated through the object for the required exposure time.
Panoramic exposures : This is also a single wall technique used for hollow circular components where the inside of the bore is accessible for centering the source point. Circumferential weld joints in pipes and pressure vessels are frequently examined using this technique. The entire joint is recorded in a single exposure. A roll film or a number of films are used with 1” overlap between successive films. Location markers are fixed at regular intervals. Identification markers are fixed as required. Minimum three pentameters must be attached at 120^0 to each other.

“Testing is a plan whivh when done repeatedly gives new or old results, we call it testing ” Dr.Hardev

Strict Control of exposure parameters is absolutely necessary.
Calculating SFD:

$$SFD = \frac{\text{Source size X thickness}}{\text{allowed unsharpness}} + \text{thickness}$$

Selecting 2 % IQI :
Wire dia = part thickness / 50
Strip thk = part thk in inches X 20
part thk in mm X 0.8 or Table

ASTM wire diameter in Inches :

Set A	Set B	Set C	Set D
1- .0032	6 - .010	11 - .032	16 - .100
2 - .004	7 - .013	12 - .040	17 - .126
3 - .005	8 - .016	13 - .050	18 - .160
4 - .0063	9 - .020	14 - .063	19 - .200
5 - .008	10 - .025	15 - .080	20 - .250
6 - .010	11 - .032	16 - .100	21 - .320

DIN penetrameter set:

1ISO - 7	6ISO - 12	10ISO - 16
3.2	1.0	0.4

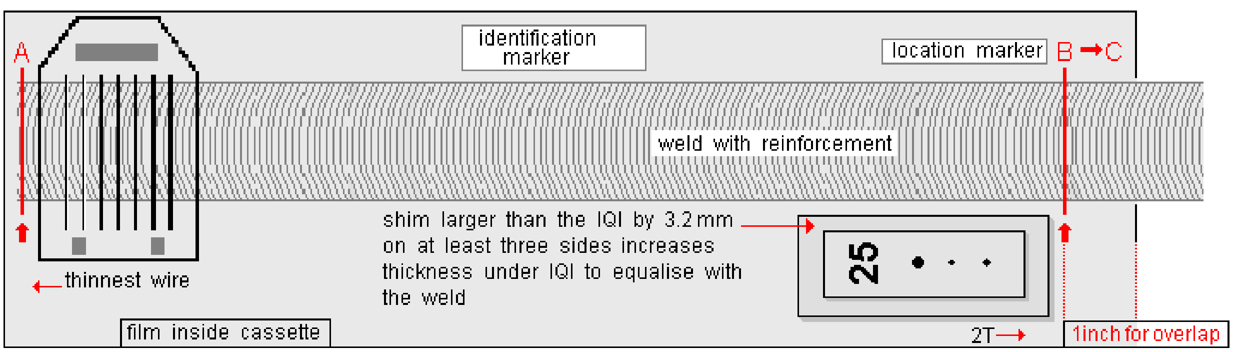
2.64	0.8	0.32
2.0	0.66	0.25
1.6	0.5	0.2
1.32	0.4	0.165
1.0	0.32	0.15
0.8	0.25	0.1 mm

Exposure time in minutes, SFD in CM :
Film Factor x $2^{thkns / HVT}$ x SFD ^{2} x 60

t = ---
Curie x RHM x 100 ^{2} or Exposure chart from the manufacturer.

“Technique is a simple and clear way to do any work in less time and achieve good skill ’’ Dr. Hardev

“Technology is the process by which humans make problems easy and simple to solve and provide a new direction by using solutions. ” Dr.Hardev



7. Radiography in a processing complex:

A processing complex such as an oil refinery or petrochemical plant is usually laid out around a pipe rack, which extends the length of the plant, usually with branches running to connect different sections of the plant. Process vessels such as heat exchangers and fractionation columns are aligned adjacent to the pipe racks, and pumps are lined up along both sides but under the pipe racks, leaving a clear pathway under the racks for access.

The layout means that a lot of equipment is located alongside the pipe racks, and the 'geography' of such plant is very convoluted.

During maintenance or construction the situation is exacerbated by the addition of scaffolding, welding machines, dismantled equipment, tool boxes, temporary piping, hoses and cables. Work can be performed anywhere in the plant, at any elevation, inside pressure equipment and ducts. A large number of trades may be involved including fitters, welders, electricians, instrument mechanics, riggers and scarf folders. All these may report to different supervisors, and there may be several different contractor teams supplying tradesmen of each type, so in a given area there may be 20 or more teams each with their own supervisor.

When a contract radiographer is employed to work in such an environment a typical approach is to assume the radiographer has full responsibility for the safety of his work. The radiographer may be required to inspect a weld over a half hour lunch break, for example. He is expected, with one assistant, to arrive no more than an hour before the job is due to start, locate the weld to be inspected, obtain his permits and set his equipment up ready on site. At the start of the break work crews leave the site. The radiographer and his assistant are then expected to rope off and post warning signs around a predetermined area which can be 50 or 60 meters across, assure themselves that the enclosed area is in fact vacated, take three radiographs on the weld, remove the rope and signs and be finished by the time the work crews re-appear. This is clearly impossible. It is only just possible to do the work necessary to perform the inspection, and simply not possible for two people to absolutely ensure that the area has been vacated, in that time. People may be working inside pressure vessels or ductwork, up in pipe racks or on or in other equipment above or around the radiography site. The complex 'geography' of a site can change from day to day as plant is built or demolished, as equipment is opened up or closed, as scaffolds are erected and dismantled. Furthermore there may be ways of inadvertently climbing over the radiation barrier rope, by climbing up on equipment which is outside the barrier, across an elevated walkway, pipe rack, scaffold or duct, and emerge in the middle of the radiation zone. It must be born in mind that in addition to the above trades there are activities such as plant inspection, or other activities of engineers, supervisors and tradesmen, that are best done during a quiet time. The radiographer simply does not have the means to adequately broadcast his intended activities, even in the unlikely event that he manages to identify and talk with all work supervisors in the area.

Taken at face value the code does not address this issue. It places responsibility only on the radiographer. To be effective this would imply that the radiographer would need to become involved at a much earlier stage to investigate and explore the work site, to discuss with his client's management what activities will be taking place around the time that radiography is to be performed and to communicate with the supervisors for every work team that may be in the area. In many instances it will still then be necessary to provide additional assistance to ensure that the area has been vacated before the source is exposed.

The objection to this approach is partially one of cost: the research required to prepare for the work would add considerably to
the time spent on the site. Where the radiography contractor is to provide additional manpower to check the area is clear costs would escalate further. But the main objection is that this approach is not practical. It is not reasonable to require a radiographer, who may only be there to perform a 30 minute task, to get to grips with the intricacies of the situation.

An alternative way is to acknowledge that prime responsibility for job safety lies with the plant manager or owner, delegated to the supervisor who has overall control of the job. This is an over-riding provision of the Queensland workplace health and safety legislation. Equivalent legislation in other states of Australia and in many other countries is similar. Indeed this is most appropriate: the owner's management team is in overall control of the work, has the best knowledge of the plant layout, the objectives of the work being undertaken and the means by which it will be performed. On the day that radiography is performed the supervisor's responsibility for safety would amount to little more than ensuring the area is vacated. He would have ample opportunity, at daily meetings etc., to keep managers, engineers and supervisors of other work in the area informed, and if necessary can arrange for assistance with vacating the area. The radiographer can focus on his own work, his prime responsibility then resting with the direct requirements of the code including confirming with the supervisor that the area has been vacated.

A further alternative often proposed is to restrict radiography to the night shift. When there is a large amount of radiography to be done this may be the only way to achieve it without disrupting the work schedule, but that is another issue. While this can help with safety caution is still necessary. Even when the plant is said to have been vacated the responsibility to assure that it is in fact vacated is unchanged. Even when others have gone there still may be some work continuing by plant inspectors and engineers or even people hiding and asleep! The urgency may be reduced compared to a lunch time shot, but the need for assurance is not. There are fewer people available to assist, and those who are on site at the end of a late shift may not be in a co-operative frame of mind.

At this refinery we have a procedure that clearly delegates prime responsibility for safety to the job supervisor. There was significant resistance to the concept at first, but this was based on poor appreciation of the practicality of leaving it to the radiographer. Where the job supervisor is a contractor the response is mixed. However if all sites had the same requirement (or, to put it another way, responded to their obligations in this regard under the workplace health and safety legislation or equivalent) it should quickly become just a part of the job.

It is recommended that the code be amended by including a reference to the over-riding responsibility of the owner in assuring that the work is conducted safely.

7.1 Radiography in a client's workshop:

Much of the background for this section comes not from direct experience but from conversations with contract radiographers. The following brief summary is intended only to give a flavor of the issue.

It is a frequent requirement for radiography to be performed in a client's workshop. The radiographer's work is often seen to be an imposition. There is little understanding of why the shop must be vacated. It would seem that in extreme cases reactions can include physical violence. However the issue here does not stop at vacating the workshop. Quite a number of contract radiographers have been surprised at the suggestion that they should enquire as to what lies behind the back wall of the workshop. It may be the next door business, or even the crib- room for the client's workshop, the workmen who have just vacated the shop now seated in a row half a meter away from where the source is exposed with only a radiation-transparent block wall for shielding.

I have suggested to various radiography contractors that they might prepare an information sheet which could help resolve these issues by encouraging effective communication and assisting their clients to prepare for the work. I am not aware that this has been done, and perhaps there are compelling arguments (legal and political) against the idea, but I have attached a suggested document (appendix 2) which may be a useful start.

Alertest 660 B. This has a lock that acts on the winding mechanism in such a way that the winding mechanism cannot be removed from the control port unless the pigtail is in the stored position. In the situation we encountered it would have taken significant time to cut through the winder cable sheath in order to recover the radioisotope. We would have had to get additional tools, which would have involved making the return trip down and back up 120 feet of cat ladder, fully in the radiation beam and with no option to choose a shielded route. But the question is, why is the control port locked at all? There is no reasonable way in which the pigtail can emerge from this end. Locking the winder does not ensure that the delivery tube is in place, and there are tales of radiographers (perhaps exhausted during a 3am shift!) failing to connect the delivery tube before winding out. It would make far more sense to place the lock at the delivery port. If it is interlocked with the delivery tube the source cannot be wound out until everything is connected. Manufacturers: please note!

(It is appreciated that an additional simple mechanism would be required to prevent the pigtail from going forward if the delivery tube is attached before the winding cable, and that this should not prevent it coming back.)

8.0 Conclusions:

The focus on safety issues in the public eye, the press and legislation is ever increasing, and the potential consequences of even a minor incident involving radiation are rising proportionally. The incidents that have occurred on our site strongly suggest that similar un-reported incidents have occurred elsewhere. Changes in attitude and action are needed.

It is not suggested that what has been proposed above is the only possible solution. The essential points are for the management of sites where radiography is performed:

To be clear as to where responsibility lies;

To ensure those responsible have understood and accepted the responsibility;

To ensure those responsible have the resources (including information) needed and are in a position to achieve what is expected.

The situation with the gamma camera lock (section 3) is, in my view, that the gamma camera lock must be installed on the delivery port instead of the control port.

9.0 SUMMARY”

Beta radiations can be absorbed completely. But X and gamma radiations cannot be absorbed completely.

Interactions of X and gamma radiations, in any material, are similar.
X and gamma radiations undergo three types of interactions in any materials:
Photoelectric effect, Compton effect and Pair production.
For energies of interest in industrial radiography, only photoelectric effect and
Compton interactions are important.
PHOTOELECTRIC EFFECT is important at low energies. It decreases as energy of

radiation increases. It increases as atomic number of the absorbing material increases.
COMPTON EFFECT is important at low energies. It decreases with energy. It does
not very with the atomic number of the absorbing material.
IONIZATION is a process, in which electrons are knocked off (removed) from an atom.
EXCITATION is a process, in which electrons are raised from an inner orbit to an
outer orbit.
Alpha, beta and gamma radiations can cause ionization or excitation. Hence, these
radiations are called IONIZING RADIATIONS.
Higher atomic number material, like lead, uranium, absorb X and gamma radiations
better than lower atomic number material, like plastic, aluminum
HALF VALUE THICKNESS (HVT) of any material reduces the radiation intensity
at a place of half of the original intensity.
TENTH VALUE THICKNESS (TVT) of any material reduces the radiation intensity
at a place to one tenth of the original intensity.

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