Safety Reports Series
No. 7

LESSONS LEARNED FROM ACCIDENTS IN INDUSTRIAL RADIOGRAPHY

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FOREWORD

Use of ionizing radiation for technical development in medicine, industry and research continues to increase rapidly throughout the world. One long established application of ionizing radiation is use of X rays and gamma rays for industrial radiography. In almost all IAEA Member States, industrial radiography is performed in enterprises ranging from multinational companies to small businesses consisting of one to two persons. In addition, radiography is performed at thousands of diverse sites, including shielded enclosures (fixed facilities) and remote field sites, and covers many different applications.

Industrial radiography accounts for approximately half of all the reported accidents for the nuclear related industry, in both developed and developing countries. This was the reason for a review of these accidents by a team of regulatory authorities, manufacturers and safety advisers. From a study of the circumstances of each accident and the apparent deficiencies in the safety, the regulatory system, the design and the personnel performance, several measures were identified that, if implemented, would improve safety performance in industrial radiography. This Safety Report contains the findings of extensive research in terms of the lessons that can be learned from accidents.

The information in this Safety Report is intended for use by those regulatory authorities, operating organizations, workers, manufacturers and client organizations responsible for radiation protection and safety in industrial radiography.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Industrial radiography is the process of using radiation to penetrate manufactured products such as casting and welded pipelines in order to determine whether flaws exist. Radiation is produced either by X ray machines or by the radioactive materials contained in small, sealed capsules. Radiation penetrates the object being studied and exposes X ray film or other detection systems placed behind the object. Industrial radiography, using X rays and radium, started in the early 1900s and application has grown tremendously, particularly since the 1940s with the utilization of manufactured sources such as ^{60}Co and ^{192}Ir.

Throughout the history of industrial radiography, accidents with some sources have occurred that have resulted in fatalities and injury. These accidents are primarily known to the small number of Member States that have the regulatory infrastructure necessary to collect information and to draw the benefits from the lessons learned. There is a need to disseminate the knowledge gained and the lessons learned from these accidents to all Member States, especially those in which the radiation safety infrastructure is weak or non-existent, so that all can benefit from the experience and implement the necessary changes in their regulatory, licensing and inspection procedures.

1.2. OBJECTIVE

This Safety Report is the result of a review made of a large selection of accidents in industrial radiography reported by regulatory authorities, professional associations and scientific journals. The review's objective was to draw lessons from the initiating events of the accidents, the contributing factors and the consequences. A small, representative selection of accident descriptions has been used to illustrate the primary causes of radiography accidents, and a set of measures provided to prevent the recurrence of such accidents or to mitigate the consequences of those that do occur.

1.3. SCOPE

This Safety Report briefly describes the scenarios of selected industrial radiography accidents, the primary causes, the lessons learned and the suggestions arising for all those persons/authorities responsible for radiation protection and safety in industrial radiography.

1.4. STRUCTURE

Section 2 contains an overview of the scenarios of selected accidents, categorized by causes, with the lessons learned discussed in Section 3. Section 4 gives a list of suggested preventive and remedial actions which, if applied, may prevent the recurrence of such accidents or mitigate the consequences of those that do occur. In the annexes, additional practical information is given, such as details of a basic training programme; a glossary of radiography terms is also provided.

2. PRIMARY CAUSES OF REPORTED ACCIDENTS

2.1. INTRODUCTION

Application of industrial radiography grew rapidly after the 1940s, and it is now used in virtually all Member States. Safety standards vary, and even though there has been significant improvement in the regulatory authority's radiation protection infrastructure in some Member States, overexposures and fatalities still occur. The dose rates that prevail close to a source or a device may be high enough to cause overexposure of extremities within a matter of seconds, and can result in the loss of a limb. Whole body exposures resulting in a fatality are rare, but they have occurred when sources have been mishandled or where they have inadvertently come into the possession of members of the public. Despite advances in equipment design and improved safety systems, accidents continue to occur: primarily, because of failure to adhere to procedures and, occasionally, because of inadequate regulatory control. Several of the more severe accidents illustrate the consequences of failure to establish adequate human, procedural and equipment controls. The International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources [1] establish the basic requirements for protection against the risks associated with exposure to ionizing radiation and for the safety of those radiation sources that may deliver such exposure. Guidance for the safe design, procedural control and operation of industrial radiography equipment is contained in Ref. [2].

One or more factors may combine to cause an accident, including an initiating event and many contributory factors. An attempt has been made to categorize the accidents by primary causes: inadequate regulatory control; failure to follow operational procedures; inadequate training; inadequate maintenance; human error; equipment malfunction or defect; design flaws; and wilful violation. At the end of each accident description, measures to prevent or mitigate the consequences of similar accidents are given.

2.2. INADEQUATE REGULATORY CONTROL

A primary cause of accidents is inadequate regulatory control, resulting from an ineffective regulatory authority or because no radiation protection infrastructure has been established. Effective regulatory control by a system of authorizations is essential if standards for the possession, use and disposal of radioactive materials, and the possession and use of X ray generating machines, are to be established. These authorizations are intended to ensure that personnel are trained, that proper equipment in good working condition is used and that written procedures incorporating radiation protection and safety considerations are in place.

Where there is inadequate regulatory control, reporting procedures and data collection are commonly inadequate.

2.2.1. Case 1: Improper disposal methods result in public exposure

In 1989, a manufacturer received a 260 GBq (7 Ci) ^{192}Ir source that had been cut off from the source assembly by the user and stored in a radiographic source changer prior to disposal. A commonly practised technique was to allow the source to decay in the source changer before being transferred to a container for ultimate disposal. Inadvertently, the source was not transferred from the source changer to the disposal container prior to the return of the source changer to the manufacturer; a radiation survey also failed to detect the presence of the source. Because the operating organization did not realize that the source was still in the source changer, it was not properly secured for transportation.

The source changer containing the source was in the transportation cycle for 3 weeks before arriving at the manufacturer's facility. Upon receipt it was discovered that there was a source in an unshielded position in the source changer. Although it is not known when the source became unshielded, it is estimated that members of the public could have received doses of up to 5 mSv, with an estimated highest exposure of 0.31 Sv to the truck drivers [3].

Initiating event

The worker forgot to remove the source from the source changer before transportation.

Contributory factors and prevention

The regulatory authority had not established adequate requirements for the disposal, tracking and transport of radiographic sources. A system should be established that accounts for all the radiographic sources, and that includes radiation surveys and physical checks.

2.2.2. Case 2: Untrained individual suffers acute radiation syndrome

In 1982, in a country with no regulatory authority, a company for non-destructive testing employed an untrained individual, i.e. someone who was ignorant of the potential health hazards of ionizing radiation, to perform radiography.

A cable drive exposure device with a ^{192}Ir source malfunctioned and the source could not be retracted into the shielded position. The worker reported the problem to his supervisor, but as it was still possible to perform radiographic exposures he was instructed to continue work. However, he soon began to suffer from what were later diagnosed as symptoms of acute radiation syndrome. His film badge recorded a dose of 5 Sv over a period of 2 weeks [4].

Initiating event

The exposure device malfunctioned.

Contributory factors and prevention

Because of the lack of regulatory control in this country, radiography took place without any licensing or regulatory requirements. These controls should include the authorization and training of workers prior to allowing them to operate radiographic equipment.

2.2.3. Case 3: Source damage caused by improper recovery

In 1976, during routine assessment, a film badge was found to have recorded 30 mSv and significant radioactive contamination. The dosimeter had been returned by a radiographer working on a pipe laying barge operating in waters that were not subject to regulatory control.

Contamination occurred as a result of improper action by the radiographer. The pipeline under construction had rolled, crushing the lead collimator on to the guide tube. Consequently, the guide tube was compressed on to the source, preventing the radiographer from retracting the source. He then used a welding torch to melt the collimator and guide tube snout to free the source. The source continued to be used until contamination on the dosimeter was reported.

In the investigation it was also discovered that the 7400 GBq (200 Ci) ^{192}Ir source was being used in a cable driven exposure device rated to hold a source of only half that activity. It was reasoned that the high activity would minimize the number of sources needed for the contract and reduce the risk of lost shipments [5].

Initiating event

The pipeline rolled on to the collimator and the guide tube, damaging the latter and preventing source retraction.

Contributory factors and prevention

Because of the absence of regulatory control, the radiographer performed an improper source recovery procedure, ultimately damaging the source. In addition, he was carrying out a job (specifically, source retrieval) for which he was not trained. This was done in order to allow the radiographer to continue with the production requirements. In addition, lack of control by a regulatory authority allowed the use of an activity source that was higher than that authorized for the device, subsequently resulting in higher doses. Use of personal dosimeters could have limited the total exposure to the operator.

2.2.4. Case 4: Unqualified personnel perform source retrieval

The investigation of Case 3 brought to light a previous accident involving the same radiographer and source assembly. On that occasion, the guide tube had not been securely fastened and had disconnected from the exposure device as the source assembly was projected. Realizing this, the radiographer attempted to retract the source. In the process, the source assembly and the control cable formed a right angle. The radiographer attempted to straighten the connection by force, but the drive cable disconnected from the source assembly and the source assembly fell into the sea. It was recovered by a diver, who was reported to have received a reward of US $1000. Allegedly, the diver took about 30 minutes to locate the source assembly, retrieving it from a depth of about 50 m in a water filled coffee can. The investigator calculated that the diver's whole body dose would have been low because of water shielding. The maximum extremity dose was potentially about 4 Sv, based on the assumptions made on the can's dimensions, the position of the source inside the can and the time taken for the diver to return to the surface. The companies concerned later stated that the diver's whereabouts were unknown and that no follow-up medical report was available [5].

Initiating event

There was an improper guide tube connection to the exposure device.

Contributory factors and prevention

Because of the absence of regulatory control, the radiographer used improper retrieval techniques. The diver was inadequately trained to perform a source recovery operation.

Cases 3 and 4 indicate a lack of regulatory control over radiography operations. In addition, they show a lack of management commitment to safety and demonstrate a lack of safety culture within the company.

2.2.5. Case 5: Unlicensed and untrained workers perform radiography

At the end of a 12 hour shift, two workers using a 1800 GBq (50 Ci) ^{192}Ir source left their base to perform repeat radiography of a butt weld located on a remote part of the construction site. They were also in a hurry, since the rest of the crew was waiting at the base to be driven back to their quarters.

After the assistant had connected the guide tube and the winding cable to the exposure device, both workers realized that their survey meter and personal radiation alarms had been left behind. They decided to proceed without monitoring equipment.

When exposure was complete, they retracted the source and disconnected the winding cable from the rear port and the guide tube from the front port of the exposure device. The guide tube was coiled up and placed, together with the source container and the rest of the equipment, in the back of their small van. They then drove back to the base to pick up the rest of the crew.

As their vehicle approached, radiation alarms went off inside the base. Those inside ran out, saw the approaching van and immediately realized that it contained an unshielded source. When the van stopped, a supervisor reached into the back, grabbed the guide tube, threw it on to the ground and then pushed a large cement roller over it as a temporary shield.

An investigation revealed the following:

(1) The two workers involved were poorly trained and unlicensed; neither had studied for or sat any examination in radiation safety.

(2) The assistant had joined the firm that day and it was the first time he had used the exposure device. Because of his lack of familiarity with the equipment, and his fatigue (at the end of a 12 hour shift), he did not correctly connect the winding cable coupling to the source pigtail coupling. As a result, the source assembly became wedged at the end of the guide tube.

(3) As a survey was not performed to verify that the source was in the shielded position, the workers were unaware of the situation [6].

Initiating event

The source assembly was not properly connected to the drive cable.

Contributory factors and prevention

The individuals performing the radiography were untrained, unlicensed and had been on an extended work shift when the accident happened. In particular, the assistant was not familiar with the equipment being used. Also, no radiation survey was performed to confirm the correct source location at the end of exposure. Despite the fact that there was a regulatory authority, the operating organization had deliberately violated regulations and employed unlicensed and untrained individuals to perform radiography. To prevent such wilful violation of regulations, regulatory authorities must perform adequate inspections, even at remote sites and at night. They must also have an effective enforcement policy.

2.3. FAILURE TO FOLLOW OPERATIONAL PROCEDURES

Failure to follow operational procedures, including the requirements of a regulatory authority, is a primary or contributory cause in the majority of accidents. This problem arises across the entire cross-section of workers, from the most senior and well trained, who may become complacent, to the less experienced and untrained.

2.3.1. Case 6: Failure to connect a safety system

In 1982, an X ray unit was replaced. At the time, the interlock on the room door was disconnected and never reconnected. One year later, a radiographer turned on the X ray unit to allow it to warm up prior to making his first exposure. He later entered the radiography room to set his film and to make final adjustments to the position of the piece to be radiographed. This involved locating the beam centre with a plumb-bob, which had to be held in the beam port with his thumb. There were no indicators inside the room to show that the X ray unit was activated. The radiographer realized that he had been exposed when he returned to the console to start the exposure and found that the beam was already on. It is estimated that the radiographer's thumb was in the beam port for about 5 seconds, which resulted in an exposure of 3.4 Sv to his right thumb and 29 mSv to the whole body. The exposure to the radiographer's right thumb resulted in erythema (burns) and blistering [7].

Initiating event

Commissioning of the new X ray unit did not ensure reconnection of the interlock system.

Contributory factors and prevention

Procedures should be in place to ensure that all systems are functional after repair or replacement. No daily check of the interlock's operability prior to use of the room was performed by the radiographer. Such a check would have alerted the radiographer to the fact that the interlock system was not functioning. A radiation survey during operations would have detected the radiation levels and prevented exposure. The radiographer ignored the warning signal on the control panel.

2.3.2. Case 7: Inadequate monitoring

In 1992, a radiographer was assigned to carry out radiography on various pipes at a construction site using a cable driven exposure device. The job required that the exposure device be suspended 6 m above the floor. After exposure, the radiographer used an aerial platform to reach the exposure device, and performed a radiation survey as he approached it to confirm that the source was in the shielded position.

The radiographer moved the exposure device to lock the source in the shielded position. He then removed the guide tube and discovered that the source was about 10 cm outside of the exposure device. The source had apparently shifted into this position when the radiographer moved the exposure device to lock it; as a result, the source had been locked in an exposed position. The radiographer was wearing his personal alarming device, but he had turned it off to conserve battery power while doing paperwork, and had not turned it back on. The radiographer received a whole body exposure of about 2.5 mSv and a maximum estimated dose to the hand of 8.8 Sv [8].

Initiating event

The source shifted as the camera was moved.

Contributory factors and prevention

A complete survey of the exposure device must be performed after locking the source in order to verify that the source is in the shielded position. In addition, the radiographer failed to follow instructions, since his personal alarming device had been turned off before radiography operations were completed.

2.3.3. Case 8: Failure to connect systems

Pipeline inspection was being carried out in a remote area using a 1300 GBq (35 Ci) ^{192}Ir source. During the setting up of the equipment, the worker failed to connect the source assembly to the drive cable. After the first exposure, the source assembly remained in an exposed position, unknown to the radiographer. After completing over 100 radiographic exposures, the darkroom technician noticed that the film from the operation was overexposed. It was discovered that the source assembly had remained in the source guide tube for about 2 hours.

No survey meter or direct reading dosimeter had been used during the work. A personal dosimeter worn by the radiographer showed an absorbed dose of 930 mSv.

The assistant radiographer's hands were in contact with the source guide tube each time preparations were made for radiographic exposure. Finger burns appeared about 11 days after the accident. The estimated dose equivalent for the finger that showed the most damage was more than 50 Sv [9].

Initiating event

Failure to make a connection of the drive cable to the source assembly.

Contributory factors and prevention

The source to drive cable connection should be verified at the start of operations. No survey of the device after each exposure was performed to verify that the source had been returned to the shielded position. Dosimetry was not used, since the direct reading dosimeter had not been worn. Direct reading dosimeters should be referred to periodically during the work shift, i.e. in this case, the direct reading dosimeter should have been read several times during the exposures.

2.3.4. Case 9: Breakage of a source assembly

In 1984, a radiographer and an assistant, working at night, wound the source assembly back into an exposure device at the conclusion of radiographic exposure. A break in the source assembly near the source capsule resulted in the source not being returned to the exposure device. No radiation surveys were carried out to ensure that the source had been returned. The equipment was sent back to the base, where another radiographer discovered that the source had remained in an exposed position. A film badge worn by the radiographer who had used the exposure device recorded approximately 150 mSv; exposure to the assistant was about 75 mSv.

The damaged source assembly was shipped back to the supplier; however, it was not adequately packed to compensate for the lost shielding (i.e. the depleted uranium sections of the source assembly) and the package had excessive dose rates at the surface. This resulted in maximum exposures to the public of about 0.3 mSv [10].

Initiating event

The source assembly broke during use.

Contributory factors and prevention

The radiographer failed to follow instructions, since the required survey to verify return of the source to the shielded position was not performed. In addition, the damaged source assembly was not packed properly nor was the required survey performed prior to transport.

2.3.5. Case 10: Defeat of safety alarms

While performing radiography in a shielded enclosure, a radiographer decided to prop open the door in order to allow air to circulate in the enclosure as he changed films and set up for the next exposure. When he did this the first time, he switched the door open alarm to the off position. This switch also defeated the enclosure radiation alarm. In a subsequent exposure, the radiographer failed to retract the 3000 GBq (81 Ci) ^{60}Co source being used. He entered the enclosure without using a survey meter and while the radiation alarms were defeated. The radiographer was not wearing a personal dosimeter. A production co-ordinator working with the radiographer also entered the enclosure; he, too, was not wearing a personal dosimeter. The radiographer changed the films, adjusted the source collimator and exited the enclosure, together with the production co-ordinator. When the radiographer attempted to crank the source out to the exposed position, he realized that the source had not been retracted on the previous exposure and that he and the production co-ordinator had been exposed.

Re-enactment of the incident demonstrated that the radiographer probably received a dose to his eyes of 90 mSv and a dose to those portions of the hand with which he had adjusted the source collimator that was in excess of 42.5 Sv. The production co-ordinator received a dose to his eyes of 40 mSv [11].

Initiating event

The interlock and radiation alarm for the enclosure were deliberately defeated.

Contributory factors and prevention

The alarm system should be designed such that defeating the door alarm does not defeat the radiation alarm. Operational procedures should have been followed to verify that the source had returned to the shielded position, and that all the appropriate dosimeters were worn. Had an alarming device been worn, the radiographer would have been alerted to the high radiation levels. The production co-ordinator's involvement demonstrates lack of an adequate safety culture within the operating organization.

2.3.6. Case 11: Failure to respond to radiation alarms

In 1993, while having difficulties in locking a radiography exposure device containing 3600 GBq (97 Ci) of ^{192}Ir, a radiographer received doses of 3 Sv to his right hand and 12 mSv to the whole body as a result of his failure to respond correctly to the warnings given by his alarming device and to the off-scale reading of the radiation survey meter. Instead of leaving the immediate area of the exposure device, he attempted to correct the problem before contacting the radiation protection officer [12], so failing to follow the operating organization's emergency procedures.

Initiating event

Difficulties were experienced in locking the exposure device.

Contributory factors and prevention

Overexposure occurred because the radiographer did not follow the established operational procedures in responding to the alarming device and the off-scale meter reading, both of which indicated a problem. Once he became aware of the situation, he should have followed the established emergency procedures of the operating organization and contacted the radiation protection officer. In responding to an emergency situation, individuals must operate within their limitations.

2.3.7. Case 12: Failure to use a survey meter and personal dosimeters

In 1990, a radiographer (who was also the radiation protection officer) and his assistant were working at a temporary job site with a radiographic device containing 3000 GBq (81 Ci) of ^{192}Ir.

Radiography operations to perform 35 exposures of welds on a waste water storage tank were planned. The source guide tube and the attached collimator were clamped on to a stand that was magnetically mounted to the exterior surface of the tank wall. The stand was moved along the weld for each successive 45 second exposure. After cranking out the source for the sixth exposure, the radiographer heard a crash and saw that the magnetically mounted stand had fallen from the side of the tank and was lying on the concrete pad. The source guide tube and collimator had been positioned approximately 3 m above the concrete pad for this exposure.

The radiographer attempted to crank the source back into the camera, but found that the drive cable could only be retracted a short distance. He then noticed that the guide tube had a loop in it. To straighten this out, the radiographer dragged the camera back by pulling on the drive cable housing. He was then able to fully retract the drive cable and consequently thought that the source was in the camera. The radiographer removed his personal dosimeter. He later admitted that he took this action to conceal the radiation exposure he thought he might have received.

The radiographer walked to the end of the source guide tube with his survey meter, but did not refer to the instrument for any indication of radiation. He grasped the end of the source guide tube with his left hand; with his right hand, he removed the tape that held the collimator in place and cast the collimator aside. He then began to unscrew the end cap from the source guide tube to exchange it for a lighter end cap assembly. As he removed the end cap, the source assembly fell out on to the concrete pad. Dose estimates indicated a whole body exposure to the radiographer of about 70 mSv and an extremity exposure of about 700 mSv [13].

Initiating event

The equipment chosen (magnetic holder) was not adequate for the environment of use. Also, it was damaged as a result of the fall from the side of the tank.

Contributory factors and prevention

As a result of the fall, the source assembly was disconnected from the drive cable. A survey of the device was not performed to verify that the source had returned to the shielded position. The radiographer then based further actions on the assumption that the source had been properly retracted. The deliberate removal of his dosimeter indicates a lack of safety culture within the operating organization.

2.3.8. Case 13: Failure to use a survey meter

In 1994, a radiographer was using a 1700 GBq (45 Ci) ^{192}Ir source in a cable driven exposure device to perform radiography on a pipeline located in a trench. At the end of the final exposure and after retracting the source, the radiographer approached the exposure device from the rear with his survey meter. He surveyed only the rear (drive cable) end of the exposure device before locking it. He then carried the exposure device to his truck (about 20 m). He returned to the pipeline to gather the films, survey meter, etc., but as he approached his truck he noticed that the survey meter showed a high dose rate. He performed a complete survey of the exposure device and found that, although he had been able to lock it, the source was not in the fully shielded position. He then fully retracted the source and locked the device.

At this time, he also became aware that his alarming device was emitting a signal. He later reported that he did not hear the alarm earlier because of the noise from the equipment operating in the area. The operator received a whole body and skin dose of 90 mSv [14].

Initiating event

The source assembly did not retract fully.

Contributory factors and prevention

The radiographer did not follow appropriate procedures and carry out a complete radiation survey. If the survey had been performed, he would have detected the high radiation dose rate on the front (guide tube) end of the exposure device and averted an unnecessary dose. In addition, the locking mechanism on the exposure device failed owing to excessive wear and allowed the source to be locked out. Daily inspection prior to use would have detected the worn lock and prevented its use.

2.3.9. Case 14: Failure to follow regulatory requirements

A radiographer and a film placer were performing radiography on insert plates in the hull of a ship. This required that the film placer enter the hull to place the films. When the radiographer received a call on his two way radio that the film placer was clear of the exposure area, he could commence the radiographic exposure.

Several hours into the work, the radiographer thought he heard the 'go ahead' signal on his radio from the film placer and exposed the source. The film placer had in fact not sent a message and was still working in the area. After about 20 seconds of exposure, the radiographer decided that perhaps he had not really heard the go ahead signal from the film placer and retracted the source. He then tried to contact the film placer, to confirm his location.

During the time that the source was exposed, the film placer observed that his survey meter was off-scale, so he exited the area to find the radiographer. There was an angry confrontation between the two operators, resulting in the film placer immediately resigning from his job. Because of the quick reaction of the film placer, his whole body dose was limited to 0.3 mSv [14].

Initiating event

Lack of communication procedures.

Contributory factors and prevention

Production pressures contributed to this event, since the radiographer was in a hurry to expose the source and did not verify that the film placer was out of the controlled area. Safety should be the primary consideration in the performance of radiography. The company used unapproved procedures for communication, since regulations require visual contact or equivalent control, such as dedicated telephone lines.

2.3.10. Case 15: Continued radiography operations with an inoperable survey meter

Under adverse weather conditions (snow and rain) a radiographer's survey meter ceased to function. Although the operator did not have a replacement, he continued to perform radiography.

Because of the weather conditions, the lock on the exposure device became jammed with ice and dirt and the source could not be locked into its shielded position. During the course of the work it was necessary to move the exposure device to different locations. As a result of the movement and because the lock was not functioning, the source shifted out of the shielded position. The radiographer was unaware of the high rate of radiation until the end of the work, when he checked his direct reading dosimeter. The operator received a whole body dose of 52 mSv [14].

Initiating event

The adverse weather conditions resulted in the failure of the survey meter and the malfunctioning of the exposure device.

Contributory factors and prevention

The radiographer continued radiography operations without a functioning survey meter. The equipment (survey meter and exposure device) was utilized beyond its design capabilities and was not adequate for the environment of use. Had an alarming device been used, the radiographer would have been alerted to the high radiation dose. If he had periodically checked his direct reading dosimeter during the work, the operator would have been aware of the high rate of radiation earlier, and his exposure reduced.

2.3.11. Case 16: Improper response to malfunctioning equipment

In 1994, a radiographer was working at night with an exposure device containing 780 GBq (21 Ci) of ^{192}Ir and had difficulties in locking it. He saw that his direct reading dosimeter was off-scale, but as his survey meter was also malfunctioning he did not detect any radiation. He struck the locking assembly with a hammer blow to achieve the locked position, and then left the unsupervised exposure device on the site while returning to the facility to collect another survey meter.

The radiographer went back to the operation site but found that he had the same problems with the locking assembly. His direct reading dosimeter was still off-scale and the new survey meter was not working properly. On returning to the facility for yet another survey meter he inadvertently left his personal thermoluminescent dosimeter (TLD) behind, and so continued working on the site without it. The TLD showed an overexposure of 8.5 mSv, which was probably received while originally manipulating the lock incorrectly [15].

Initiating event

Difficulties were experienced in locking the exposure device.

Contributory factors and prevention

The radiographer failed to follow safe operational procedures when the equipment malfunctioned. Specifically, he attempted to repair the exposure device using unapproved procedures; did not confirm the operability of the survey meter provided; disregarded his off-scale dosimeter reading; left the device unattended at the client's site; and did not wear a personal dosimeter. If the radiographer had performed any of these required tasks, he could have minimized his exposure.

2.3.12. Case 17: Exposure inside a pipeline

A radiographer had a permit to carry out X ray radiography on a pipeline at a gas compressor station. A barrier clearly identified the extent of the controlled area, and pre-exposure and exposure warning signals were given before the work commenced.

Several exposures had already been made and the X ray tube was still energized when the radiographer saw two men emerge from a hole further along the pipeline. Enquiries revealed that they also had a permit to work, had been inspecting the pipeline internally, and had crawled through the X ray beam twice while performing their inspections.

Reconstruction of the incident revealed that the inspectors had each received a dose of 0.2 mSv [5].

Initiating event

Lack of co-ordination of the work to be performed on the site.

Contributory factors and prevention

The radiographer did not maintain the required control of the area, resulting in exposure to two individuals. The radiographer must obtain all the necessary co-operation and information from the site manager prior to the start of operations in order to be able to maintain control during all radiography operations. The required controls (barriers and warning signals) of the access points to the controlled area were not adequately maintained.

2.3.13. Case 18: Death caused by the alleged mishandling of radiographic sources

In 1992, a radiographer died from radiation induced leukaemia following several years of treatment for previously unrecognized radiation injury to his extremities. The individual had worked in industrial radiography since 1974, received adequate training, and had more than 20 years of experience in using torch type devices and remotely operated exposure devices. His personal monitoring equipment showed a minimal whole body exposure of 100 mSv during his occupational lifetime. Dose investigation after his death demonstrated that he had received exposure in excess of 10 Sv. His right hand had received more than 100 Sv, necessitating amputation. Although all the evidence suggests that his symptoms were radiation induced and caused by work with gamma sources, it has not been possible to establish how the exposures occurred. It is hypothesized that he received the excessive exposure from removing source capsules from source assemblies using shielding and a hacksaw [16].

Initiating events

It is hypothesized that the individual had performed unsafe operations with the radiographic sources, which resulted in the excessive dose.

Contributory factors and prevention

Lack of detection of the high exposure indicates that the radiographer's dosimeter had not been worn properly, which is a violation of regulatory requirements and operating procedures.

2.3.14. Case 19: Lack of radiation surveys results in excessive exposure

In 1990, a radiographer and his assistant were using a 3000 GBq (80 Ci) ^{192}Ir source to perform radiography at a temporary work site. Unknown to the radiographer, the source became disconnected and remained in the guide tube. After completing two exposures, the radiographer went to develop the film, while the assistant dissembled the equipment and moved the exposure device to the next location. While doing this, he placed the source guide tube around his neck and walked approximately 20 m. When he set the equipment down, the source assembly fell from the guide tube.

The assistant notified the radiographer, who called the radiation protection officer; the latter instructed the two workers to perform source retrieval, and the source was safely shielded. The estimated whole body exposure to the assistant was 0.24 Sv and that to the radiographer, 0.18 Sv. The assistant experienced erythema and tissue damage on the neck; the estimated dose to the skin of the neck was 50 Sv.

During radiography no radiation surveys were performed and the assistant radiographer was not wearing his personal dosimeter [17].

Initiating event

The source assembly became disconnected from the drive cable.

Contributory factors and prevention

The excessive exposure to the assistant radiographer was a direct result of not having performed the required radiation surveys. Had they been carried out, the disconnected source would have been detected earlier and placed in a shielded position, thereby preventing excessive exposure to the neck of the assistant.

2.3.15. Case 20: Deaths from radiation overexposure

A serious accident occurred in 1984 in which eight members of the public died of overexposure from a radiographic source. A 1100 GBq (30 Ci) ^{192}Ir source became disconnected from the drive cable and was not properly returned to its shielded container. Subsequently, the guide tube was disconnected from the exposure device and the source eventually dropped to the ground, where a passer-by picked up the tiny metal cylinder and took it home. Although the exposure device was marked with the international radiation caution symbol, the source itself bore no markings. The source was lost from March to June and a total of eight persons, including the passer-by, members of his family and some relatives, died; the clinical diagnosis was 'lung haemorrhage'. It was initially assumed that the deaths were from poisoning. Only after the last family member had died was it suspected that the deaths might have been caused by radiation [18].

Initiating event

The source assembly became disconnected from the drive cable, fell to the ground and was left at the work site.

Contributory factors and prevention

No radiation surveys were performed to ensure that the source had returned to the fully shielded position. Had these been carried out the problem would have been disclosed and the accident may have been prevented. Also, the passer-by did not recognize the potential health hazard associated with the source. The consequences might have been mitigated if the source had had warning signs on it.

2.4. INADEQUATE TRAINING

The second most common cause of reported accidents is inadequacy of training, including ineffective initial and refresher training programmes, and also unqualified personnel such as assistant radiographers working without supervision.

2.4.1. Case 21: Chest injury resulting from lack of training

An individual received radiography training over a 2 week period, including discussions with a senior radiographer. At the end of the second week, he was allowed to work without supervision.

He was provided with a 900 GBq (25 Ci) ^{192}Ir source held in a shutter type container and sent to work on a gas pipeline. He was the last radiographer to complete his radiographs and was left alone on the site. He placed the source container on the front passenger seat of his car when returning to the facility. Upon arrival, a fellow worker noticed that the source container shutter was open and that the radiation beam was directed towards the driver's seat.

Reconstruction of the event estimated an average whole body dose of 450 mSv, with 2.15 Sv to the left hip. Eight months later it was learned that the radiographer was receiving medical treatment for a serious injury to the chest wall, just below the left nipple. Additional smaller burns were apparent in the centre of the chest, his left wrist and the fingertips of the left hand. Although the injuries were clearly radiation induced and had been received at about the same time as the initial exposure, none of the injuries was consistent with the initial exposure investigated. The main injury could have been caused either by the open exposure device being held close to the chest for about 19 minutes, or a completely exposed source being held at 10 mm for about 12 minutes. The most plausible explanation was that the source had been removed from the container and placed in the radiographer's shirt pocket for a short time. The radiographer never admitted that this had taken place.

The lesion on the chest wall was approximately 5 cm in diameter and 3.5 cm deep, and probably resulted from a dose in excess of 20 Sv. The destroyed tissues, including two damaged ribs, were surgically removed and replaced by a metal plate to protect the heart [19].

Initiating event

The radiographer did not have adequate training to work without supervision.

Contributory factors and prevention

Insufficient supervision of the radiographer was apparent and no confirmation of the adequacy of training was given. In addition, use of equipment that allows the source to be inadvertently removed may have contributed to this event.

2.4.2. Case 22: Overexposure resulting from the disregard of an alarm

A radiographer was exposed to high doses of radiation as a result of the source shifting during movement of the exposure device. No mention was made in the accident report of a survey meter being used. The operator was wearing a personal alarming device which did send out a signal, but he decided that the dosimeter was malfunctioning and so turned it off for the duration of the work. The radiographer received a whole body dose of 30 mSv.

Initiating event

The source shifted during movement of the exposure device.

Contributory factors and prevention

The radiographer did not believe or have trust in the radiation detection equipment, which indicates that he did not understand the radiation hazard or the function of the detection equipment. This can be traced back to inadequate training [14].

2.4.3. Case 23: Overexposure resulting from inadequate training

In 1985, an industrial radiographer was accidentally exposed to a high dose of ionizing radiation from a ^{192}Ir source assembly during the radiography of weld joints in gas pipelines. A company engaged an unskilled local labourer to carry out this work. He was neither trained in radiation protection nor was he aware of the hazards associated with ionizing radiation. In addition, no provision was made for personnel radiation monitoring or area monitoring.

During radiography, the source had stayed in the exposed position and did not return to its shielded position after the first exposure. However, the radiographer continued his work, unaware of the hazard. After 18 exposures, he stopped work and developed the film. It was discovered that 17 of the 18 films were black, indicating that the source had been in the exposed position the entire time. The estimated exposure was 24 Sv to the hand and 2–3 Sv to the whole body [20].

Initiating event

An untrained individual was allowed to operate the exposure device.

Contributory factors and prevention

No personnel dosimetry or radiation survey meters were provided. The untrained individual was allowed to operate without supervision.

2.4.4. Case 24: Radiation burn resulting from inappropriate retrieval

In 1994, a radiography crew, using 3500 GBq (95 Ci) of ^{192}Ir, experienced difficulty with the source exiting from and retracting into the exposure device. In trying to retract the source to the shielded position after a radiograph it was apparent from the survey meter readings that the source was in an unshielded position. In working the crank, the source was pushed from but would not retract into the exposure device, which indicated a source disconnect. The radiographer obtained a 2.5 cm thick lead sheet from the radiography truck and covered the source in the guide tube. It was dark when the radiographer had his helper rope off a large area around the source. He then asked the client to call the company's radiation safety officer to tell him that everything was under control and that the radiographer could handle the situation.

The radiographer then disconnected the guide tube and the source assembly fell into the mud at the bottom of a ditch. In picking up the source from the mud with channel-lock pliers, the source assembly slipped; in attempting to align the source assembly to the exposure device, the radiographer apparently touched the source. He then pushed the source assembly back into the exposure device, mistakenly placing the connector end instead of the source capsule in first. Thus, the latter was located outside the exposure device, as indicated by the survey meter readings.

The radiographer then removed the source assembly and placed it under the lead sheet. He removed the lock box from the exposure device, inserted the source end of the source assembly into the exposure device, replaced the lock box and locked it. The source was now secured in the shielded position. The barricades were taken down, the equipment was loaded on to the truck, and the crew returned to the office. The company did not notify the regulatory authority of the disconnect.

About 10 days later, the radiographer experienced discomfort in his left thumb and index finger, and visited a doctor for treatment on three separate occasions. The radiation protection officer and the radiographer visited the regulatory authority's office and reported the incident. Investigations showed a whole body exposure of 10.5 mSv.

Inspection of the exposure device was performed by the radiography company's radiation safety officer the day after the incident and it was found that a similar, but incorrect, source assembly had been provided and used in the exposure device [21].

Initiating event

The source became disconnected from the drive cable.

Contributory factors and prevention

Overexposure occurred when the radiographer performed procedures for which he was not properly trained. Individuals must recognize their limitations and operate within their capabilities. In this case, the individual did not know the proper techniques or the correct tools to be used in this source recovery, i.e. a 6 inch pair of pliers was used rather than a pair of longer length. The shielding used was inadequate to substantially reduce the radiation levels present. Daily inspection would have detected the incorrect source assembly prior to its use.

2.5. INADEQUATE MAINTENANCE

Numerous events are caused by inadequate inspection and maintenance of radiographic, ancillary and safety equipment. Failure to meet the manufacturer's recommended level of maintenance may result in wear, damage and breakdown of essential components. Inspection of equipment prior to its use will detect unsafe conditions such as loose fittings and crushed guide tubes. These should be corrected prior to performing radiography.

2.5.1. Case 25: Failure of a device lock after improper maintenance

In 1993, a radiography event was reported that involved a camera locking mechanism which came apart from the exposure device. This allowed the 3600 GBq

(98 Ci) ^{192}Ir source to be pulled from the exposure device. The incident occurred after midnight, when two radiographers working in low light were performing radiography.

The films were taken for development and the radiographer removed his film badge and placed it on his clipboard, thinking his work had been completed. However, several shots had to be retaken, but for these he forgot to put back his film badge.

To move the exposure device from the first to the second retake location, the radiographer took hold of the crank cable in his left hand and lifted the exposure device with his right hand. He took a few steps and the drive cable fell from the exposure device to the ground. He placed the exposure device on a truck tailgate, thinking he had a disconnect. He picked up the crank-out approximately 100 cm from the end, and moved his hand quickly towards the connector end. He grabbed what he thought was the cable connector and brought it to within 15 cm of his face. When he realized it was the source, he dropped it, alerted his partner and ran from the area.

Re-enactment of the scenario and calculation of the radiation exposure indicated that the radiographer had received an estimated whole body and lens of the eye exposure of 6 mSv. A worst case extremity exposure to the fingers was estimated to be 19 Sv.

The lock insert of this exposure device is held in place by two roll pins. One was missing, and may have been missing for some time, while the second was in the camera housing but not inside the lock insert. This allowed the lock insert, the spring and the movable insert to be pulled from the lock box. The drive cable was connected to the source assembly, but when the lock insert was pulled from the lock box the drive cable also pulled the source assembly from the camera, thereby exposing the source [22].

Initiating event

The roll pins that secure the lock insert were missing.

Contributory factors and prevention

The radiographer made the assumption that he had a source disconnect. He did not confirm the actual situation with a radiation survey meter. A proper inspection and maintenance programme would have detected the missing roll pin and had it replaced. Daily inspection may have detected the looseness of the lock insert prior to performing radiography. In addition, removal of a film badge before concluding radiography and not using monitoring equipment are violations of regulatory requirements and indicative of a lack of safety culture.

2.5.2. Case 26: Damaged guide tube results in a wedged source

The source assembly of an exposure device became wedged in a cut in the guide tube. The damage to the guide tube was not detected prior to its use. The radiographer, in attempting to retrieve the source assembly, disconnected the guide tube and shook it violently with both hands. Three fingers of the left hand and two fingers of the right hand were exposed. The estimated finger dose was 8.8 Sv and necessitated amputation of the injured fingers. The estimated whole body dose was 0.1 Sv [23].

Initiating event

The cut in the guide tube caused the source assembly to become wedged and to remain exposed.

Contributory factors and prevention

Daily inspection would have detected the cut in the guide tube prior to use and prevented the source becoming wedged. The resulting source recovery was not performed properly by the radiographer.

2.5.3. Case 27: Inadequate maintenance causes overexposure

A radiographer and his assistant were working with a 3000 GBq (80 Ci) ^{192}Ir source. When the exposures were completed, the assistant dissembled the equipment, placed it on the truck and returned to base. Upon arrival, he carried the exposure device from the truck to the storage facility. While placing the exposure device on the shelf, he tilted it and the source assembly fell on to the floor. The radiation alarm in the storage facility alerted him to the hazard, and the source was subsequently recovered and safely shielded.

Investigations showed that the exposure device had not been properly maintained. The spring loaded latch, designed to secure the source in the fully shielded position, was not working; the latch had been jammed in the unlocked position by dirt. In addition, the radiographer had neither placed the shutter control in the off position nor had he installed the dust cover cap on the front of the exposure device. A combination of these circumstances led to the source falling on to the floor [6].

Initiating event

The lock was jammed in the open position.

In addition to the lack of maintenance, which caused the lock to fail, secondary securing requirements were not fulfilled, i.e. turning the shutter to the off position and installing the dust cover cap. Had either of these steps been taken, the source would not have dropped out of the exposure device.

2.6. HUMAN ERROR

Even if equipment is functioning properly and effective operating procedures are established, the safe operation of radiographic equipment relies heavily on the radiographer's judgement and response. The probability of human error increases during work under adverse and stressful conditions, e.g. fatigue caused by night work, low light and high noise environments, production pressures and physical exertion. The probability of human error may also increase with substance use, misuse or abuse.

2.6.1. Case 28: Inappropriate response caused by panic

A radiographer and an assistant were using a 740 GBq (20 Ci) ^{192}Ir source to radiograph butt welds in a steel pipe at a field site near a fabrication plant. At the end of exposure, the radiographer attempted to retract the source assembly back into the exposure device. When the assistant walked towards the pipe to change the film, his alarming device went off. His survey meter registered off-scale (>1 mSv/h). He ran back to the crank handle located behind the exposure device and wound it back and forth a few times to try to move the source assembly back into the exposure device. Because a longer source assembly had been used than that designed for the exposure device, radiation levels that were higher than those expected were present at the front of the device as the source was not in the fully shielded position. This led the radiographer to believe that the source assembly had not been fully retracted.

The two workers attempted to reduce the exposure rate by driving their van to a point between the exposed source and the road, to act as a shield. During his rapid exit from the van, the radiographer left the hand brake off and the gear lever in neutral. This resulted in the van rolling down a slope into a wire mesh boundary fence, damaging both the fence and the vehicle. While running back to his partner, the assistant dropped and damaged his radiation alarm.

The workers then decided to shield the source by dropping the exposure device, the guide tube and the controls (drive cable, crank) down a hole in the ground about 20 m from the site. Their plan was to share the dose by taking turns pulling the exposure device by the control cable (drive cable) towards the hole.

During their first attempt, the survey meter was dropped and broken. The remaining serviceable radiation detector, a personal alarm (beeper), was interpreted as indicating that the source had not been fully retracted. Eventually, they used a personal alarming dosimeter at the front of the exposure device and verified that the source was in the shielded position. The radiographers loaded the equipment into the damaged van and drove to the nearest hospital, where they requested treatment for radiation sickness.

Although no overexposure occurred, the risk of injury from an accident caused by their panic was high, and the monetary losses were significant [6].

Initiating event

The survey meter reading was off-scale.

Contributory factors and prevention

The personnel panicked and did not attempt to take a proper radiation survey to confirm the radiation levels. This could have been done by moving some distance away from the source in order to obtain an on-scale radiation reading, and then by using the inverse square law to determine the actual source location. The radiographers recognized there was a problem and formulated a plan. However, based on their improper responses it is apparent that they did not have the proper training to handle an emergency. Training in proper emergency response could have helped to reduce the level of panic and to resolve the situation more quickly.

2.6.2. Case 29: Exposure device lost during transport

A radiographer was putting his equipment away upon completion of a job at a fabrication yard. He placed the exposure device on the truck's rear bumper, but forgot it there when he drove back to the office. He noticed that the exposure device was missing when he unloaded the equipment. By retracing his route with a survey meter on the dashboard, he was able to locate the exposure device and source assembly. The former was damaged when it fell on to the road, and the source assembly dislodged. The unshielded source assembly was found close to the exposure device [24].

Initiating event

The operator forgot that he had placed the exposure device on the bumper of the truck and drove away.

Contributory factors and prevention

Forgetfulness is part of human nature, but a system of double checking, such as a written checklist, might have prevented the accident.

2.6.3. Case 30: Equipment damaged because of production pressure

While performing radiography with a 3000 GBq (80 Ci) ^{192}Ir source in a cable driven exposure device on the welds of a heat exchanger during refinery shutdown, the guide tube came into contact with an unshielded welder's high voltage cable. The electricity from the welder's cable ground through the guide tube and exposure device. The guide tube melted as a result of the heat generated, and the source assembly could not be returned to the exposure device by normal means. The faulty welding cables had been noted earlier, but nothing had been done to correct the situation.

Whole body doses of 1.5 mSv were received by the radiographers involved in source retrieval. One operator also received burns to his hands as a result of the heat generated by the electric current [14].

Initiating event

Faulty welding cables coming into contact with the guide tube caused the latter to melt.

Contributory factors and prevention

This situation occurred as a result of production pressure and work continuing even with faulty welding equipment. In addition, two tasks, welding and radiography, were being performed in the same area within a limited time without co-ordination. The radiographer must evaluate the work environment and assess and correct any known hazards prior to performing radiography. This also includes ensuring that co-ordination between other tasks is considered; this should be done in conjunction with the client organization.

2.6.4. Case 31: Accidental exposure of two radiographers

Two radiography teams were working at opposite ends of a large manufacturing workshop. One team prepared a panoramic X ray tube head to radiograph a circumferential weld on a large cylindrical vessel. The other team took a longer time to set up an identical X ray machine to radiograph a number of test welds. Both the X ray control panels and the warning systems were in the centre of the workshop, out of direct sight of the teams. Therefore, as an added safety measure during the preparation phase the cables from the X ray tube heads were disconnected from their respective control panels.

When the preparations were completed, the radiographer on the first team instructed his assistant to connect the cable and initiate a 7 minute exposure. A pre-exposure audible warning sounded and an exposure warning light was activated in the centre of the workshop. The team left the area for the duration of exposure and, upon returning, the radiographer immediately noticed that his assistant had connected the wrong cable to their control panel. The other team, still setting up test pieces, had continued working, unaware that their X ray tube head had been energized.

The dosimeters of the exposed radiographers recorded doses of 39 mSv and 18 mSv, which were significantly lower than would have been predicted by calculations. Statements from the radiographers and reconstruction of the incident provided the explanation. The two radiographers had worked with their backs to the tube head, and repeatedly in a crouched position. Their lumbar regions were not only closer to the tube head, and therefore in the beam longer than the dosimeters pinned to their chests, but their bodies also shielded the dosimeters. Direct radiation measurements and special dosimetry provided estimated whole body doses of 600 mSv and 160 mSv, respectively [5].

Initiating event

The wrong control cable was connected to the control panel, and thus the wrong X ray unit was activated.

Contributory factors and prevention

A combination of human error and the design of the control panel allowed exposure to take place. The radiographer should have verified that the proper connection was made to the correct unit. The panels should be so designed that interchangeability is not possible. When more than one crew are working simultaneously, work must be co-ordinated between crews.

2.7. EQUIPMENT MALFUNCTION OR DEFECT

Although manufacturing defects are not common, they do occasionally occur. In addition, malfunctions can occur as a result of the conditions of use.

2.7.1. Case 32: Crank-out equipment failure

A regulatory authority was notified that a radiographer was unable to retract a 2700 GBq (73 Ci) ^{192}Ir radiography source to its fully shielded position. The incident resulted from a crank-out failure caused by separation of the inner liner between the control housing and the gear box assembly. The source was returned to the shielded position by cutting the control housing near the gear box and pulling the source back into the shielded position with the inner drive cable. No overexposure resulted from the incident [25].

Initiating event

The inner liner separated from the control housing because of a defect.

Contributory factors and prevention

Although there was an equipment problem, it was possible to recover and secure the source without overexposure when appropriate recovery operations were performed. All malfunctions and defects should be reported to the manufacturer so that an investigation can be made to determine the cause of the defect, and appropriate actions taken.

2.7.2. Case 33: Defective locking mechanism

A 200 GBq (6 Ci) ^{192}Ir radiographic source assembly fell out of an exposure device because of a defective locking mechanism. The exposure device was being transported on a trolley back to a storage room after use. The radiographer failed to notice the loss of the source, but two young canteen workers found it and picked it up. They saw the danger marking on the source and reported their discovery. The dose to fingers was estimated to be about 8 Sv, while the whole body dose was less than 0.2 Sv [26].

Initiating event

The lock was defective and allowed the source to fall out of the exposure device.

Contributory factors and prevention

The radiation hazard warning on the source helped to identify the hazard quickly and to minimize the dose to the public. As a result of this event, an advisory notice was sent out to other users in order to alert them to the potential problem with the lock.

2.7.3. Case 34: Disconnect caused by a defective connector

In 1993, a radiographer was working with an exposure device containing a 1600 GBq (43 Ci) ^{192}Ir source. After the operation, he retracted the source assembly but detected with his survey meter that it had in fact not been retracted. Analysis of the accident showed that the male connector of the drive cable was broken. It had been exchanged some days before by the manufacturer, but the new connector was also defect.

The radiographer informed the radiation protection officer of the accident and the source was retrieved correctly; a whole body dose of 0.5 mSv was received [15].

Initiating event

The male connector of the drive cable broke, causing a disconnect.

Contributory factors and prevention

The routine radiation survey immediately detected the problem and the appropriate emergency procedures were followed. As a result, no overexposure occurred.

2.7.4. Case 35: Source leaks that contaminated equipment and personnel

A radiographer was alerted to a high dose rate by his alarming device when rolling in the guide tube while packing up his equipment. He then surveyed the guide tube with his survey meter and obtained readings of 5–6 mSv/h.

A detailed radiation contamination check was made and the guide tube, the drive cable and the radiographer's hand and forearm were found to be contaminated. The contaminated equipment was sealed in plastic bags and disposed of. Contamination was washed off the operator's hand and forearm. No overexposure resulted from this incident.

An investigation by the regulatory authority found that the cause of the contamination was leakage from the source because of a faulty weld during encapsulation [27].

Initiating event

A faulty weld had remained undetected during manufacture of the source.

Contributory factors and prevention

The manufacturer's quality control was not rigorous enough to detect the defect. Use of a doubly encapsulated source significantly reduces the risk of a leaking source. The radiographer's correct response to the abnormal level of radiation prevented the spread of contamination.

2.8. DESIGN FLAWS

Although design flaws are not common, they do occasionally occur. Design changes result from field experience and from ongoing development by the manufacturers, users and regulatory authorities.

2.8.1. Case 36: Separation of a depleted uranium shield in an exposure device

During a routine radiation survey of an exposure device that had recently been refurbished, the radiography found a narrow beam of radiation measuring 17 mSv/h at 15 cm from the bottom of the device. The exposure device was immediately removed from service and returned to the supplier for repairs. No overexposure resulted from the event.

Examination of the exposure device revealed that the two halves of the uranium shield had separated because of overtorquing of the retaining bolts [28].

Initiating event

The bolts to hold the shield assembly were overtorqued during refurbishment.

Contributory factors and prevention

Because the manufacturer was notified, the design was changed to a one piece uranium shield; for existing units that have a split shield, the procedures were modified to reduce the possibility of a gap forming. Exposure devices that could have this defect have been checked, and operators notified of this possibility. Although a manufacturing defect was present, routine procedures detected a problem before it could develop into a potentially hazardous situation.

2.8.2. Case 37: Source lost from a pneumatically operated container

In 1977, a 260 GBq (7 Ci) ^{192}Ir source fell out of a pneumatically operated exposure device at a construction site and was not detected by the radiographer because of a faulty survey meter. A construction supervisor picked up the source, which he assumed to be a component of a mobile crane, and placed it in the left breast pocket of his shirt. He travelled home in a bus with six others. Later that day he became nauseous and vomited, removed his shirt and went to bed. The source remained in close proximity to the bed in the room where the worker, his wife and their 6 year old son were sleeping.

Loss of the source was discovered the next day, when a search was initiated by the construction firm with the aid of survey meters. A replica of the source capsule was shown to workers on the site, with subsequent identification and recovery of the source from the bedside table.

Estimations of dose were made and it was determined that the supervisor's child had received a whole body dose of 0.1 Sv and his wife, 0.17 Sv. The construction supervisor was estimated to have received 10 Sv to the thumb and index finger of the right hand and 5 Sv to the thumb, index and middle finger of the left hand, all of which required amputation 2 years later. Also, he was estimated to have received between 50 and 100 Sv to the chest wall, which needed skin grafting [29].

Initiating event

The design of this particular type of pneumatic exposure device allowed the source to fall out of the exposure device to an unexposed position.

Contributory factors and prevention

Failure to perform a proper survey, because a faulty survey meter was used, resulted in overexposure to members of the general public. The regulatory authority of the country concerned banned the use of this particular design to prevent any future accidents.

2.8.3. Case 38: Source disconnect

In 1989, a 1400 GBq (38 Ci) ^{192}Ir source assembly was disconnected from the source drive cable in the guide tube. The disconnect was attributed to the hook mechanism that connects the source assembly to the drive cable. After retracting the source, the radiographer was alerted to the high dose rates. In successfully recovering the source, the radiographer received a maximum whole body dose of 2.2 mSv [30].

Initiating event

The disconnect occurred because a source connector was used that could be easily disconnected.

Contributory factors and prevention

With improvements in technology, most manufacturers produce safe equipment. Regulatory authorities should periodically review incidents and identify recommendations for use of equipment and/or procedures. In this case, the regulatory authority recommended changing the design to a ball type connection.

2.9. WILFUL VIOLATION

Training, equipment design and implementation of effective operating procedures cannot prevent an individual from deliberately violating safety procedures. The probability of these deliberate acts increases when working under stressful conditions, e.g. substance abuse, fatigue, economic factors, production pressures or physical exertion. Wilful violations are more likely to occur in those operating organizations in which no strong safety culture exists.

2.9.1. Case 39: Overexposure during a source capsule assembly change

An attempt was made to interchange sources between two pneumatically operated exposure devices by projecting the sources to the end of the source guide tubes, changing the guide tubes between the exposure devices, and then retracting each source into the other exposure device. However, because of a defective pump, confusion on the part of the radiographers and poor source changing procedures, control of both sources was lost. The exact sequence of events is not known, but during the resulting source recovery the following procedures took place: one source guide tube was cut and a wire was run through it in an attempt to return one of the sources to its exposure device; one source fell on to the ground and was not discovered for some time. It is possible that at one point both sources were in the same source guide tube. In the process, one radiographer received an exposure of 37 mSv, but the exposure to the other two radiographers is not known exactly, since they removed their personal dosimeters when they knew that a problem had arisen. On the basis of the known radiation exposure and re-enactment of the scenario, each radiographer was assumed to have received a dose of 38 mSv [31].

Initiating event

The initiating event was the wilful performance of a source exchange that was not carried out according to approved procedures.

Contributory factors and prevention

The radiographers became confused during the source exchange and the subsequent source recovery operation, adding to the dose they received. In addition, lack of clear operating procedures to perform source exchange contributed to the confusion. Removal of the required personal dosimeters is a wilful violation of established requirements.

2.9.2. Case 40: Theft resulting in public exposure

In 1991, a 26 GBq (about 1 Ci) ^{192}Ir source assembly stored in a lead shield and an empty exposure device were stolen from the storage pit. The theft went unnoticed for several days and the regulatory authority was unable to identify the thieves. The source assembly changed hands many times and was recovered ultimately at a scrap dealer's shop. The scrap dealer's estimated maximum whole body dose was 200 mSv. The maximum dose to any individual in the public is estimated to be 35 mSv [26].

Initiating event

Theft of radioactive material by an individual.

Contributory factors and prevention

Adequate physical security should be provided based on the local conditions and as determined by the regulatory authority. The individual who stole the radioactive material was not familiar with the health hazards of ionizing radiation and this contributed to the gravity of the dose.

2.9.3. Case 41: Untrained individuals who performed radiography without supervision

In 1993, an operating organization deliberately violated the established rules by allowing untrained individuals to perform radiography. As a result, two untrained workers (not supervised by a radiographer) received whole body overexposure of 20 mSv from a radiographic source disconnect. Neither individual was wearing an alarming device. Hand exposure to one of the workers was calculated to be 900 mSv.

The individuals were not familiar with the operation of the equipment or the proper use of the survey instruments, since the company had not provided sufficient training and allowed them to work unsupervised [24].

Initiating event

Untrained workers were allowed to operate radiographic equipment.

Contributory factors and prevention

The individuals worked alone without any supervision of their operations, which might have mitigated the consequences. The operating organization performed a wilfully negligent act by allowing untrained personnel to operate radiographic equipment.

2.9.4. Case 42: An untrained individual who performed radiography without supervision

In 1995, a company allowed an untrained individual to perform radiographic work at night with a 1900 GBq (51 Ci) ^{192}Ir source.

During operations, the worker was not able to retract the source into the safe shielded position. He recognized the problem and tried to communicate with the radiation protection officer of the facility, but was unable to reach him. He finally contacted personnel of the regulatory authority and the event was resolved. The individual received a maximum whole body dose of 2.1 mSv [15].

Initiating event

An untrained worker was allowed to operate radiographic equipment.

Contributory factors and prevention

The individual worked alone without any supervision. Although this person was not qualified, he recognized the problem, performed the appropriate actions and therefore did not receive an overexposure. The company performed a wilful act of negligence by having an untrained person perform radiography.

2.9.5. Case 43: Theft of a radioactive source

Radiography, using a 300 GBq (8 Ci) ^{192}Ir source, was performed at a height of about 8 m from the ground at the construction site of a thermal power station. The radiographer fixed the source for a 1 hour panoramic exposure of a joint in a pipe. At about 23:20 hours he posted a watchman to keep on eye on the source while he went to check whether a second joint was ready for radiography. On his return 30 minutes later, he found that the source was missing. He neither reported the matter to his supervisor immediately nor did he try to monitor the area because he did not know how to use the survey meter. The matter was reported to the supervisor only the next morning, 6 hours after the incident. A search for the source took about 4 hours; it was found hanging approximately 8 m from the original exposure location (16 m from the ground).

Ten days after the incident, a construction worker, who had worked in the same area between 24:00 hours on the day of the accident and 06:00 hours the following morning, complained about the appearance of a black spot on his chest. Later, this spot developed into a wound of about 18 × 8 cm. Another small wound also appeared near to his elbow. It was revealed that this person had slept on the mesh platform from which the source had been found hanging. It appears that someone had moved the source and then left it attached to the mesh, with one end tied to a wire. The source might have been close to the exposed worker and later, as a result of his movement, may have shifted into a vertical hanging position. The person injured may have received a maximum dose of 10 Sv locally, and the person who moved the source, a few millisieverts. Other persons working in the vicinity of the source might have received a few tens of microsieverts [26].

Initiating event

The source assembly was deliberately moved.

Contributory factors and prevention

Inadequate security of the source assembly allowed the source to be moved. In addition, the delay in reporting the loss contributed to the excessive dose.

3. LESSONS LEARNED

Lessons have been learned from the findings of the investigations made into accidents involving industrial radiography. These are briefly summarized as follows:

(1) Adherence to established safety procedures would have prevented most of the accidents. Failure to follow established safety procedures frequently occurs because of commercial pressures and production requirements, e.g.:

    (a) In most of the overexposures, the individual concerned failed to follow the appropriate procedures, specifically the failure to perform an adequate survey;
    (b) In several of the overexposures, safety interlocks or other safety systems had been deliberately defeated, contrary to established procedures;
    (c) In several of the overexposures, unqualified personnel were inadequately supervised by a radiographer.

(2) Safety may be compromised if the regulatory controls that encompass licensing, inspection and enforcement are not in place. These controls include consideration of device and source design, radiation safety procedures and training. Where these were not adequately considered, unsafe conditions resulted, including radiation exposure to several members of the public, e.g.:

(a) The failure to review device design has resulted in source disconnect and exposure to members of the public;
(b) In regions outside the jurisdiction or in remote outposts of a regulatory authority, procedures have fallen short of the acceptable standards.

(3) Management can quickly lose control of the level of knowledge and performance of radiographers unless systematic audits are conducted, adequacy of training is assessed and employees are retrained, e.g.:

(a) In several cases, the radiography personnel involved in accidents were allowed to use radiographic and safety equipment without the necessary training;
(b) Radiography personnel involved in accidents frequently failed to use a radiation survey meter, or did not use it correctly;
(c) Radiography personnel involved in accidents often failed to wear the required personal dosimeters.

(4) In many cases, a poor safety culture resulted in the degradation of safety systems and operating procedures. It appears that workload and production costs take precedence over safety, e.g.:

(a) During some source retrievals, radiography personnel deliberately removed dosimeters before the recovery actions in order to avoid an increase in the dose registered;
(b) Some accidents occurred owing to lack of care in the maintenance of safety systems and equipment;
(c) Evidence was found of a high level of complacency in personal safety and in the care of others;
(d) Frequently, an inadequate number of qualified radiography personnel is available to cope with the prevailing conditions.

(5) Training was found to be deficient in the majority of accidents. This deficiency covers initial safety training as well as training in proper emergency procedures, e.g.:

(a) Source retrievals were attempted without the proper equipment or planning, and under unfavourable environmental conditions;
(b) Radiography personnel involved in accidents sometimes lacked a basic understanding of the fundamental operating principles of the devices with which they were working;
(c) In general, there appears to be a lack of knowledge of the basic principles of radiation safety;
(d) Radiography personnel failed to implement basic operational and safety principles under stress, i.e. their knowledge is not ingrained.

4. PREVENTION AND REMEDIAL ACTIONS

4.1. REGULATORY AUTHORITY

The importance of a well established regulatory authority cannot be overemphasized. Provisions should be made not only for its creation but also for its continuous development and improvement.

The regulatory authority needs:

(1) To ensure that the appropriate legislation is in place to control the radiation safety of industrial radiographic equipment; this legislation needs to be adequate in order to cover the operating organization, supplier and manufacturer;

(2) To ensure that the conditions of the regulatory authorization are maintained, including:

   (a) A requirement that a radiation safety officer be appointed by the operating organization, particularly for training personnel and for advising on radiation protection issues;
   (b) A requirement that periodic safety audits be performed;
   (c) A requirement that a reporting system be set up through which timely reports of abnormal events and the experience gained therefrom would be obtained.

(3) To take prompt, vigorous and consistent enforcement action when violations of requirements occur or where unsafe conditions are found;

(4) To recognize its limitations and to ask for external assistance, e.g. from the IAEA or experts in the field, as necessary;

(5) To review their rules, codes of practice and guides periodically and to update them to meet current standards;

(6) To ensure that adequate resources or arrangements are made for the safe disposal and decommissioning of facilities, as applicable;

(7) To ensure that safety inspections, audits and assessments are carried out, including unannounced field site inspections;

(8) To develop an effective communications network such that all the relevant parties are notified promptly of matters pertinent to the safe conduct of radiography.

4.2. OPERATING ORGANIZATION

The operating organization is responsible for the possession and use of the industrial radiographic sources and devices. This includes their operation in accordance with regulatory authority regulations, permits or authorizations, or appropriate international safety standards such as the Safety Report on Radiation Safety in Industrial Radiography [2].

Therefore, the operating organization bears the prime responsibility for the safety of industrial radiography. Management should exercise leadership in developing and maintaining a safety culture throughout the entire organization.

The operating organization needs:

(1) To notify the local regulatory authority as soon as possible of the intent to purchase and use radiographic devices, and to submit other notifications as required by the regulatory authority;
(2) To appoint an experienced radiation protection officer who is competent to develop and implement a radiation safety programme;
(3) To ensure that the resources necessary for maintaining a radiation safety programme and compliance with the requirements of the regulatory authority are committed;
(4) To develop and implement a training programme that at least covers:
    (a) The basic radiation safety principles and safety procedures;
    (b) The requirements of the regulatory authority;
    (c) Specific device related training and supervised hands-on experience to include radiographic equipment, survey meters, remote handling tools and personnel dosimetry;
    (d) Emergency procedures, including practice runs;
    (e) Human factor considerations resulting from environmental conditions, substance abuse, fatigue and stress;
(5) To seek, if appropriate, the advice of the manufacturer on equipment malfunctions, source retrievals and equipment service;
(6) To prepare, document, implement and audit a preventive maintenance programme as defined by the regulatory authority, or as recommended by the IAEA or the manufacturers;
(7) To ensure that all operational, maintenance and safety related instructions are available in the local language(s);
(8) To prepare, document, implement and audit emergency procedures, including training as approved by the regulatory authority, or as recommended by the IAEA, in the absence of a local infrastructure;
(9) To notify the regulatory authority of any intended device modification that may affect safety prior to its implementation (and in the absence of a local infrastructure, to seek the advice of the manufacturer);
(10) To conduct a safety review that includes procedures, training and audits of work and equipment at least annually, and to document the results; records

should be available to the regulatory authority for review (if a communication concerning the safe conduct of radiography is received from a manufacturer, supplier or regulatory authority, a review of its applicability should be held as soon as possible);

(11) To implement procedures as recommended by the manufacturers or suppliers to maintain the integrity of the equipment and to ensure that the equipment complies with the latest regulatory requirements, or IAEA recommendations.

4.3. RADIOGRAPHER

The primary responsibility for personal safety lies with the radiographer. In addition, vigilance is essential if the safety of other workers and the general public is to be ensured. The radiographer needs:

(1) To have an understanding of the effects and hazards associated with radiography;
(2) To have the necessary training and qualifications to perform the tasks required;
(3) To ensure that the appropriate procedures are followed without exception;
(4) To have a comprehensive knowledge of the devices being used;
(5) To have a comprehensive knowledge of the safety equipment and systems necessary to perform the tasks required;
(6) To wear his/her personal dosimeters at all times when handling or using radiographic equipment;
(7) To ensure that all the equipment used is maintained to the prescribed standards, as defined by the regulatory authority and in conjunction with the manufacturer's recommendations;
(8) To ensure that sufficient resources are readily accessible to cover emergencies;
(9) To have adequate emergency response training;
(10) To take on the responsibility for reporting unsafe conditions or practices to the radiation protection officer and/or to the regulatory authority;
(11) To refuse to perform procedures that are beyond his/her knowledge, or are beyond the capability of the equipment.

4.4. DESIGNERS AND MANUFACTURERS

Designers and manufacturers bear the primary responsibility for carrying out research, testing and examination to ensure the safe design of shielded enclosures, equipment and systems. These organizations need to provide sufficient detailed information to assist users in the development of operating, maintenance and emergency procedures. In addition to these major responsibilities, the manufacturers and designers need:

(1) To assist the IAEA and its Member States in facilitating the training and the regular retraining of radiography personnel; this should include the training of regulatory authority personnel in understanding the equipment;
(2) To maintain communication with the regulatory authorities and to advise them on suggested modifications to existing equipment, as well as on operational experience;
(3) To advise the IAEA if there is any difficulty in establishing contact with the regulatory authorities, so that points of contact can be established and communications improved;
(4) To ensure that source, radiographic and ancillary equipment designs comply with the prevailing relevant design standards, and that appropriate authorizations are obtained;
(5) To keep users up to date with operational experience, information and findings related to safety, equipment improvements and safety related modifications to the equipment;
(6) To provide comprehensive operating manuals for the equipment, and to assist in any necessary training;
(7) To respond promptly to user problems, and to implement appropriate actions to address these problems.

4.5. SITE OPERATOR (CLIENT)

Industrial radiography is often performed on sites, locations and premises that are not owned by the operating organization (radiography company). The client often controls the site, co-ordinates the activities of all the service companies employed there and may exercise considerable commercial pressure on each service company, including the one selected to perform the radiography.

In exercising these responsibilities, the client needs:

(1) To ensure that the operating organization is given sufficient lead time prior to the work in order to enable any required advance notifications to be given to the regulatory authority.
(2) To make certain that contractual conditions do not impose impossible burdens on the selected operating organization; for example, the need to set up barriers and to satisfy other conditions for safe working may limit the number of radiographs that can be reasonably practicable to produce within the time available; regulatory and safety requirements should take precedence.

(3) To ensure that the operating organization employed has the necessary expertise and appropriate ancillary equipment, e.g. monitoring instruments, barriers and emergency equipment, to work competently and safely, as evidenced by the appropriate regulatory authority authorization; the judgement of the operating organization needs to be respected and its advice relied upon to ensure safe working practices.

(4) To make certain that radiography is co-ordinated with other work on the site; for example, to ensure that the radiographic warning signals to be used do not have different established meanings on the site (which could confuse personnel), and that radiography is scheduled to be done so that the necessary area can be evacuated and made secure. A 'permit to work' method is a control that can be used, and all sections and levels of the workforce need to be informed about the safety issues that concern radiography, and when it is to take place.

(5) To ensure that, if possible, the necessary space is provided for the operating organization to safely and securely store radioactive materials. Control of the radiographic work areas needs to be given to the radiographers. Where necessary, supporting security staff may be needed to prevent access to a controlled area.

Annex I

RADIATION PROTECTION TRAINING PROGRAMME FOR RADIOGRAPHERS

I–1. TRAINING

Training for radiographers consists of both practical and classroom work. The regulatory authority sets the contents of the curriculum, the standards and the acceptable level of education for entry into the training programme. All training is given by bodies approved or authorized by the regulatory authority. All training is specific to the radiation sources and the equipment used.

I–2. PRACTICAL TRAINING

This part of the training programme covers hands-on operation of equipment. It is performed under the direct, continuous control of an experienced radiographer, and includes standard operating and emergency procedures.

Upon completion of practical training, the proof and quality of training are documented as follows:

(1) A work log that describes the procedures performed and the equipment used;
(2) A description of the various work site operations, including the dose record for each period;
(3) A commentary from the trainer as to the trainee's competency and the authenticity of the work log.

I–3. CLASSROOM TRAINING

This part of the training programme covers:

(1) Basic radiation physics.
(2) A description of what radiation is and where it comes from, including the generation of X rays; the concept of decay and half-life should be included.
(3) The types of radiation.
(4) The characteristics of alpha, beta, gamma, neutron and X ray radiation.
(5) The units of radiation measurement.

(6) A description of the use of and relationship between the units used to quantify the dose, the dose rate and the radioactivity.
(7) Detection and measurement of radiation.
(8) The function, purpose, use and limitations of the following equipment: (a) recording dosimeters: a TLD, a film badge and an electronic dosimeter; (b) a direct reading dosimeter; (c) a personal alarming device; and (d) survey meters.
(9) Dose reduction, optimization and the ALARA principle, with a description of the use of time, distance and shielding, including calculations using the inverse square law, half-value and tenth-value layers.
(10) Regulatory knowledge, which covers information on all the applicable regulations and licence conditions relevant to workers. Trainees must be aware of their obligations and the scope of the regulatory authority. This section also includes information on other regulations that will affect radiographic work, i.e. transportation, packaging and workplace safety.

I-4. CERTIFICATION OF RADIOGRAPHERS

The following conditions need to be satisfied for certification:

(1) Acceptance by the regulatory authority or other approved entity of the documents of practical training;
(2) Assurance that there are no other reasons to prevent the applicant from being certified;
(3) Successful completion of a written examination, as authorized by the regulatory authority or other approved entity.

I–5. MAINTAINING RADIOGRAPHER CERTIFICATION

Standards have to be established for maintaining radiographer certification, including consideration of changes in the regulatory requirements, as well as the radiographer's work record, duties and retraining requirements.

Annex II

CONSIDERATIONS FOR THE SAFETY OPERATING PROCEDURES

The radiographer needs to understand that regulations are in place to limit radiation exposure, thereby limiting the risk of potential health hazards.

Performing radiography safely begins with the operating organization establishing and supporting a strong radiation safety programme, including effective training and retraining, adequate equipment and resources, and a commitment to safety.

It is essential that this commitment to safety is understood by all the employees so that a proper attitude towards safety is adopted and safety becomes an integral part of their work. Positive feedback from management reinforces this safety culture and attitude. The radiographer implements strong safety practices on a daily basis and understands that not performing safely will have a direct impact on his/her health, and possibly that of co-workers. The radiographer takes responsibility for his/her own well being, as well as that of others.

The following actions can help to ensure that this personal responsibility for safety is implemented on a daily basis.

(1) Prior to operating the radiographic equipment, perform a thorough inspection to ensure that all the components are in good working order;

(2) Before using an exposure device, make a reference survey of the device to verify that the radiation survey meter is operable; this also provides a reference radiation level that can be referred back to after each exposure in order to verify that the source is returned to the shielded position;

(3) Never assume the position of the source; the source position must always be confirmed by using a survey meter;

(4) Ensure that all the appropriate equipment to perform the work is obtained and used;

(5) Verify that the equipment obtained is appropriate for the specific work and environmental factors, including any specialized equipment, e.g. stands, clamps and magnetic holders;

(6) Visually inspect the environment where the radiographic work is to be done in order to detect and correct any potential problems, e.g. objects that could fall and crush a guide tube, and low lighting conditions;

(7) Employ a series of double checks with other radiographers if possible, e.g. verify that connections have been made; do not assume that any step has been taken;

(8) Survey the guide tube end or beam port area of the exposure device after each exposure, and while securing or moving the exposure device;

(9) Keep the supervisor informed of all the problems encountered, e.g. with the equipment, procedures, safety issues and work site;

(10) Do not perform any work or emergency procedures for which training has not been received or for which the appropriate equipment is not available;

(11) Follow standard operating procedures;

(12) Wear all the required dosimeters properly, this being the most direct method for indicating the amount of radiation received by individuals; this provides information on the doses received and can indicate a potential problem with the technique used;

(13) Believe the survey meter and the alarming devices when they indicate high radiation levels; always assume the worst, since it is better to err on the side of safety, e.g. an off-scale meter means that the source is exposed, but remain calm, think and take appropriate actions;

(14) Do not let production pressures dictate the work schedule; safe operations should take priority;

(15) Have a sound knowledge of the expected radiation levels and respond to unusual levels or indications;

(16) Do not attempt to modify the equipment;

(17) Do not attempt to repair the equipment unless trained and authorized to do so.

Annex III

EMERGENCY PLAN

III–1. INTRODUCTION

Accidents have occurred and continue to occur in industrial radiography, therefore it is essential that operating organizations prepare an effective written emergency plan. This has to be authorized by the regulatory authority. The plan has to include the foreseeable types of emergency and to outline the responses and safety equipment necessary, to deal with each type of emergency. The plan is prepared in consultation with the radiation protection officer. Management has to ensure that all the radiographers have a sound knowledge of the plan, since it is they who must initially assess the hazards and assist in initiating the emergency plan.

III–2. EMERGENCY EQUIPMENT

The following emergency equipment needs to be made readily available:

(1) Material of a composition that is sufficient to attenuate by a factor of at least 100 all the gamma radiation emitted by the source when the material is directly positioned over the exposed source capsule. Table III–I provides the approximate thicknesses of material needed to reduce the radiation levels to 1/100 of their original value.
(2) Tools suitable for severing the source guide tube and the drive cable from the remainder of the exposure device.
(3) Tongs, with a handle of at least 1.5 m, that are suitable for the safe handling of the source if it is separated from the exposure device outside the normal course of operation, and an emergency shielded container, i.e. a lead pot.

TABLE III–I. THICKNESSES OF THE MATERIAL NEEDED TO REDUCE THE RADIATION LEVELS TO 1% (cm)

Shielding material	Source	
	Ir-192	Co-60
Lead	3.5	8.5
Steel	6.0	15
Concrete	32	46

III–3. SOURCE RETRIEVAL PROCEDURE

One of the most common emergency situations encountered is a source disconnect. Source retrieval is a highly skilled operation and has to be performed on appropriate equipment by those persons trained to do so in order to keep radiation doses to personnel and the public to the minimum.

The following steps, if taken, could minimize radiation exposure during an emergency:

(1) Once the emergency situation is recognized, stop and think;
(2) Carry out a radiation survey of the area and set up barricades, as required;
(3) Verify the location of the source using a survey meter;
(4) Seek advice from the radiation protection officer in planning source retrieval.

The plan should be prepared taking into consideration the dose restrictions (time, distance and shielding). Notify the regulatory authority, as required.

When preparing the retrieval plan, the radiographer must deal with the situation with which he/she is confronted.

(a) Examples and suggestions of how to deal with each scenario

(i) A source that has remained in the collimator may indicate that a disconnect has occurred. There is no need to move the barriers, since the dose rates will be the same as those used during the radiography operations. The collimator will shield the source, so addition of further shielding is not a priority. Connectors on the drive cable and the source capsule assembly should be inspected for wear or damage to determine whether a reconnect is possible. If not, tongs can be used to move the source capsule assembly back into the exposure device.

(ii) A source that is wedged in the guide tube will require moving of the barriers, since the dose rates will have increased. Placing shielding material over the source is of primary concern. This must be done with as little exposure to the radiographer as possible and can be accomplished by using whatever is available to remotely place the shielding over the source. Ropes and poles can be used to position the shielding, as well as any on-site equipment such as cranes. The proper placement of shielding over the source must be confirmed with the survey meter. The point at which retrieval attempts should cease must be clearly understood. This point is determined on the basis of the experience and knowledge of the radiographers involved, the equipment available, and the doses of the persons concerned.

(b) *Retrieval of source*

The retrieval plan should be followed; any deviation could lead to confusion and result in unnecessary doses. The position of the source must be confirmed with a survey meter after every attempt or action, since this might have caused the source to move. While a radiographer is working near a shielded source, no attempt should be made to move the source by its drive mechanism. This could cause the source to move out from underneath the shielding and result in a high dose to the radiographer working near the source. Direct reading dosimeters should be read at regular intervals to avoid any possible overexposure. The return of the source to its shielded position in the exposure device or alternate shielded container has to be confirmed by a radiation survey of the device or container.

(c) *Post-retrieval*

All the radiographic equipment associated with an emergency should be removed from service until its proper function can be determined. The source has to be leak tested to ensure that no damage to the source couple has occurred. All doses to those persons that are involved in the emergency should be determined and recorded. All the required reports have to be submitted to the appropriate authorities within the prescribed time limits. The information and experience gained through the emergency should be shared with other radiographers and all relevant partners.

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GLOSSARY

This glossary contains terms as used in gamma radiography.

acute radiation syndrome. The medical term for radiation sickness. See radiation sickness.

ALARA. In relation to exposures from any particular source within a practice, except for therapeutic medical exposures, protection and safety shall be optimized in order that the magnitude of individual doses, the number of people exposed and the likelihood of incurring exposures all be kept as low as reasonably achievable, economic and social factors being taken into account, within the restriction that the dose to individuals delivered by the source be subject to dose constraints.

alarming device. A small electronic instrument worn by a person that sounds an alarm when a high radiation dose rate is encountered or when a certain radiation dose rate has been exceeded.

ancillary equipment. The equipment required to safely expose the source, including guide tubes, control cables and a crank, and specialized equipment such as collimators and rigid source stops.

attenuation. The reduction in the intensity of radiation as it passes through any material, e.g. through lead shielding.

becquerel (Bq). The SI unit of activity equal to one disintegration per second: 1 Bq = 1 dis/s.

calibration. Verification of a radiation survey meter to ensure that it reads the radiation dose rate accurately. A known radiation source must be used for proper calibration.

camera. See radiographic device.

chronic exposure. Exposure persisting in time.

collimator. A small radiation shield of lead or other heavy metal used in radiography. A collimator, which is placed on the end of the guide tube, has a small opening through which a narrow cone of radiation escapes when the source is cranked into the collimator. Use of a collimator can greatly reduce the size of the controlled area to which access must be restricted.

control cable. See drive cable.

crank-out cable. See drive cable.

crank or crank handle. The handle used to crank the drive cable, which in turn cranks the source into or out of the cable driven exposure device.

direct reading dosimeter. A device worn by a person that gives an instantaneous reading of the dose absorbed. It may be an air ionization chamber or electronic device, e.g. pocket dosimeter, pen dosimeter.

dosimeter. A device used to determine the radiation dose a person has received. It may be a direct reading dosimeter, a thermoluminescent dosimeter, a film badge or, in some cases, an electronic dosimeter.

drive cable. A cable used to push out and retract a source in a cable driven exposure device. It usually operates with a crank or push–pull mechanism. Also called a control cable.

exposure device, cable operated. A radiographic exposure device where the source capsule assembly is cranked or pushed out of the shield by a cable to make the radiographic exposure.

exposure device, pneumatically operated. A radiographic exposure device where the flow of air moves the source capsule out of the shield to make the radiographic exposure.

exposure device, radiographic. A shielded container designed to hold a radiographic source. A means is provided to move the source capsule assembly outside the shield or to remove part of the shield to make the radiographic exposure. Also called a radiography camera.

film dosimeter. A type of dosimeter that uses film to record the dose received.

fixed facility. See shielded enclosure.

gamma radiography. Industrial radiography using radioactive materials that emit gamma radiation.

half-life. The time it takes for half the atoms in a radioactive source to decay. Half-lives vary from a fraction of a second to billions of years. The half-lives of ^{60}Co and ^{192}Ir are 5.3 years and 74.2 days, respectively.

half-value layer. The thickness of a material that reduces the amount of radiation to one half of its original activity. The thickness of the half-value layer depends on the material and on the radiation energy.

industrial radiography. Use of penetrating radiation, such as X rays or gamma radiation, to inspect metal castings or welds for internal flaws. Industrial radiography does not include medical uses of radiation, e.g. for chest or dental X rays.

leak test. A test performed to verify if radioactive material is being released from the source capsule. See contamination.

lock box. That part of a radiographic exposure device which contains the mechanism used to lock the source capsule assembly into a safe shielded position. Also known as the 'lock assembly'.

non-destructive testing. Testing or examination of an object to detect the presence or absence of flaws without damaging the specimen. Examples of non-destructive testing methods are industrial radiography, ultrasonic testing, magnetic particle testing and dye penetrant testing.

nozzle. Metal tip at the end of the source guide tube of a pneumatically operated exposure device.

overexposure. A radiation dose that is in excess of legal regulatory limits.

panoramic radiographic exposure. Radiographic exposure in which film is exposed in a 360° angle around the source, e.g. if the source is in the centre of a pipe, a panoramic exposure will radiograph the entire circumference of the pipe.

personal dosimeter. Dosimeter worn by an individual to record his/her dose.

pigtail. That part of a radiographic source assembly which includes the short cable and the connector, but not the source capsule.

pocket dosimeter. See direct reading dosimeter.

qualified expert. An individual who, by virtue of certification by appropriate boards or societies, professional licences or academic qualification and experience, is duly recognized as having expertise in a relevant field of specialization, e.g. medical physics, radiation protection, occupational health, fire safety, quality assurance or any relevant engineering or safety speciality.

radiation burns. Burns in flesh caused by ionizing radiation. These are not caused by heat, but by chemical breakdowns in the nuclei of living cells. However, in effect radiation burns are medically similar to heat burns.

radiation sickness. Sickness resulting from receiving large exposure to radiation.

radiation survey. As used in this publication, a radiation survey is measurement of the levels of radiation taken by a survey meter.

radiographic source. Any source of radiation where the radiation is produced by the decay of radioactive materials such as ^{192}Ir and ^{60}Co, or electrically produced, as in X ray machines, and used for radiography.

radiograph. Picture of an object made by penetrating ionizing radiation that passes through the object, exposing photographic film. Details of the inside of the object will be visible on the film.

radiographic exposure device. See exposure device.

shielded enclosure (fixed facility). An enclosed space engineered to provide adequate shielding from ionizing radiation for those persons that are in the vicinity. Its use allows radiography to be performed in a small, easily secured controlled area within a facility.

shielding. Material that can be placed around a radiation source for the purpose of reducing radiation levels. See attenuation.

source assembly. The radiographic source, including the source capsule, the cable, the locking ball and the connector. In the case of the pneumatically operated and pipeline exposure devices used in this text, the assembly comprises only an inner and outer source capsule.

source changer. A shielded container with at least two holes for sources. The old source is placed in one hole of the changer and the new source is removed from another.

source guide tube. A hollow tube that guides and protects the radiographic source as it is moved out of and retracted back into its shielded position in the exposure device.

survey meter. A portable instrument that measures the radiation dose rate.

TLD. See thermoluminescent dosimeter.

tenth-value layer. The thickness of a material that reduces the amount of radiation to one-tenth of its original intensity. The thickness of the tenth-value layer depends on the material and on the radiation energy.

thermoluminescent dosimeter. A dosimeter that contains a radiation sensitive crystal which responds to radiation.

X ray radiography. Radiography using X ray machines as the source of radiation.

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