RADIOLOGICAL INCIDENTS IN INDUSTRIAL GAMMA RADIOGRAPHY IN THE PHILIPPINES, 1979-1993

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ABSTRACT

Among the many practices of radiation sources, the practice of industrial gamma radiography in the country has the most number of reported radiological incidents. During the past fourteen (14) years, from 1979-1993, twenty (20) incidents that had occurred were reported to the Institute.

This paper presents the nature and extent of the 20 reported incidents as well as the results of the analysis of why these incidents happened. The results of the analysis showed that the causes of these incidents are mainly human error and equipment failure. Hence, the factors that can minimize or prevent the chance of occurrence and/or recurrence of incidents and in minimizing the hazard in case of radiological incidents are: a) proper training and re-training of personnel; b) proper and regular inspection and maintenance of equipment; c) adequate radiation survey; and d) proper storage and inventory of the radiography sealed sources.

INTRODUCTION

Radiation sources are extensively used in industries for a variety of applications such as Industrial Gamma Radiography, Nucleonic Gauges, Gamma Irradiators, Radiotracers Studies, etc. Among these uses, industrial radiography is the practice which causes the larger number of radiological incidents in the country. A radiological incident poses a severe radiation hazard that may cause biological effects to the person or persons involved and not only the people directly connected
with the activity but also those of the population involved by chance. Previous studies showed that the following clinical effects were observed after a person was involved in a major radiological incident in industrial gamma radiography: hand oedema, formation of vesicles, slight atrophy of finger, chest inflammation, blistering necrotic tissue, erythema of thighs, skin lesions, burns on many fingers, etc.

Industrial gamma radiography is the process of using gamma radiation to "see" inside manufactured products such as metal castings or welded pipelines to find out whether the products contain flaws [1] (refer to Appendix A for the detailed description of the operation).

The Philippine Nuclear Research Institute (PNRI) is the government agency mandated to regulate the uses of radioactive materials in the country. The Institute issues license to users of radioactive materials, conducts periodic inspections of licensed users, implements appropriate enforcement actions when regulations are violated and unsafe situations occur, and investigate all cases of radiological incidents. Presently, there are 24 licensed companies in Industrial Radiography who possess 60 radiographic exposure devices and employ a total of 48 Radiological Health and Safety Officer (RHSO)/Assistant RHSO, 121 radiographers, 81 radiographer’s assistants, and 46 trainees.

Any incident whether minor or major, has to be reported and investigated to determine its causes which will become the basis for making the corrective actions to prevent or minimize the occurrence/recurrence of the incidents and to minimize the hazard. Likewise, the incident could be a basis for re-evaluating and improving the radiation safety program of the radiography company involved.

This study aims to identify the causes of incidents during radiographic operations and to determine the factors that can prevent or minimize the recurrence of the said incidents. Twenty (20) radiography incidents that occurred in the country from 1979 to 1993 were analyzed. The analysis was carried out using the information contained in the Overexposure investigation Report form (see Appendix B) submitted by the radiography companies involved in the incident. The written report is evaluated, followed by these additional procedures: a) interview of personnel involved, b) ocular inspection of the facility and audit of procedures, and c) submission of a final report.
The results of the study show that human error and equipment failure are the main causes of radiological incidents in industrial gamma radiography. The factors that could help in minimizing the chance of occurrence/recurrence of radiological incidents and in minimizing the hazard in case of radiological incidents are:

a. proper training and re-training of personnel;

b. proper regular maintenance and inspection of equipment;

c. adequate radiation survey; and

d. proper storage and record of source.

CASE HISTORIES AND INVESTIGATION PROCEDURES

Documented reports of twenty (20) incidents involving industrial radiography sources that occurred in the country between 1979 and 1993 were evaluated and analyzed. The cases are presented in Table 1.

These incidents were reported to the Philippine Nuclear Research Institute (PNRI) through the NRLSD by the licensed radiography companies using the overexposure investigation report form. In order to determine the veracity of the reports, interview of the personnel involved in the incident and an ocular inspection of the location where these incidents actually happened were carried out. Below are the steps conducted in order to have a factual and detailed assessment of the incident.

a. Submission of Investigation Report

Licensed radiography companies are required to report to the Institute any incident involving the licensed radioactive material and/or loss of sealed source within twenty (24) hours from the discovery of the loss/incident. A subsequent written report detailing the circumstances of such loss and/or incident and the corresponding actions undertaken shall be submitted to the Institute within thirty (30) calendar days. These reports are submitted using the overexposure investigation report form which are evaluated and analyzed to determine the correctness of the data and circumstances of the event.
b. Interview of Personnel Involved

The personnel whose names appeared in the report and the Radiological Health and Safety Officer (RHSO) are invited to the Institute for personal interview regarding the incident. The said personnel are required to narrate the circumstances that lead to the occurrence of the incidents. They are also interrogated on matters which are not clear in the report. Clarification and verification of the exactness of the reported data are obtained.

c. Ocular Inspection of the Facility and Procedures

The investigation team, with the approval of the company involved, conducted an ocular inspection of the facility in the exact location where the incident happened. This inspection is carried out if the investigating person is not satisfied with the written report and the data on hand. It is being done only after the written report was evaluated and personnel involved were interviewed. Re-enactment of the incident was carried out during the inspection. Based on the re-enactment, the causes of the incident and the estimated absorbed dose of personnel involved are noted and checked against the submitted data and the results of the evaluation of the film badges. Compliance with the approved operating and emergency procedures are observed.

The human and technical errors that caused the incidents are identified. After these, the radiography company involved in the incident are required to submit the corrective actions to be taken to prevent the recurrence of the incident.

d. Submission and Approval of Final Report

The investigation team prepared the final report containing the evaluation and recommendations of the investigation. This report was submitted to the Chief of the Nuclear Regulations, Licensing and Safeguards Division for approval.

The licensed radiography company was notified of the results of the investigation and the decision of the approving authority. The radiography company required to implement the corrective actions which they developed and as approved by the Institute. The company or persons involved could be suspended depending upon the degree of the incident and the violations of the conditions.
of their license which resulted from the incident and/or have caused the incident.

CAUSES OF RADIOGRAPHY INCIDENTS

Analysis of the 20 radiography incidents that occurred between 1979 and 1993 showed the following causes and percentage of occurrence:

- Violation of operating and emergency procedures .......... 34.21%
- Improper maintenance and inspection .......... 31.57%
- No proper radiation area monitoring ........... 10.52%
- Improper handling of RAM ................. 7.89%
- Source pigtail material deficiency ........ 5.26%
- Violation of incident reporting ............ 5.26%
- Improper storage ................................ 2.63%
- Theft .............................................. 2.63%

CONCLUSION

The twenty radiological incidents that happened during industrial radiography operations in the country from 1979 to 1993 showed that human error and equipment failure are the main causes of these incidents, 47.8% are due to human error and 52.2% are due to equipment failure.

The following are the main factors attributing to the human error:

a. inadequate training;

b. failure to conduct radiation survey;

c. failure to maintain and inspect the equipment; and

d. improper execution of operating and emergency procedures.

The following are the main factors attributing to the equipment failure:

a. source get disconnected from the drive cable;
a. source get disconnected from the drive cable;

b. source is jammed inside the guide tube; and

c. rupture of source pigtail assembly.

The factors that could help in preventing or minimizing the chance of occurrence and/or recurrence of radiological incidents and in minimizing the hazard in case of radiological incidents are:

a. proper training and re-training of personnel;

b. proper regular maintenance and inspection of equipment;

c. adequate radiation survey; and

d. proper and adequate storage and record of source.

It could be noted, however, that all the incidents presented are considered minor since the sealed sources have not been damaged in the course of the incident and the recovery have been affected without anyone receiving a dose in excess of the dose limits and the number of persons exposed are small.

RECOMMENDATION

1. Strict enforcement by PNRI regarding reporting the incidents;

2. Regular effective inspection by PNRI of the implementation of radiation safety program of all radiography companies;

3. Radiography companies, utmost commitment in complying with the provisions stipulated in CPR Part 11, "Licenses for Industrial Radiography and Radiation Safety Requirements for Radiographic Operations;" and

4. Continuous investigation and documentation of incidents in radiography regardless of its degree.

BIBLIOGRAPHY

ACKNOWLEDGEMENT

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Appendix A

Radiography

A defect in a weld between two sections of a pipeline or some other flaws in a casting or metal component could have catastrophic consequences when the pipeline or object is put to use. Radiography reveals such imperfection using the unique properties of ionizing radiation to penetrate these important components without damaging them. The radiographer produces a radiograph which is a permanent photographic record of the non-destructive test (NDT). The procedure is also called quality assurance (QA) testing [2].

![Diagram of a radiographic arrangement](image)

**Figure 1: Diagram of a radiographic arrangement**

**Radiation used for radiography:**

Gamma radiography uses gamma radiation. The necessary equipment is highly portable and ideally suited to the sometimes remote and often difficult working conditions in construction sites.

Iridium-192 is ideal for radiography but other radionuclides can be used depending on the characteristics of the object material.
Operational Features [3]:

a. Source Assembly: A sealed radioactive source capsule is swaged to one end of a short flexible steel ‘pigtail.’ At the other end of the ‘pigtail’ are swaged a stop ball used to secure the pigtail in the projector and the female portion of the cable connection. (see Fig. 2)

Note that the source connector is designed so that the source cannot be exposed unless the source assembly is properly coupled to the drive cable.

The ‘available length’ of drive cable must exceed the total length of the guide tube(s) so that the source can be projected to the source stop.

The source itself must not be touched under any circumstances and may be approached only when it is safely shielded in the projector or source changer.

b. Projector: The source is shown in the stored position in the ‘S’ tube at the center of the shield of a source projector. (Fig. 3)

A drive cable control unit is shown with its drive cable coupled to the source pigtail. Compact depleted uranium shielding is used in the projector to give good protection with minimum weight.

The ‘S’ tube minimizes radiation from the exit port when the source is properly stored. A lead-filled shipping plug is screwed into the exit port and this is removed only during radiography operations.

The source must not be projected until the equipment is properly connected and all personnel have left the restricted area.
c. Transit: Rotating the crank of the drive cable control unit in the 'EXPOSE' direction (counter-clockwise) moves the source out of the storage position in the projector and into the guide tubes (Fig. 4). The radioactive source is under positive mechanical control using the drive cable control system. The maximum operating distance is achieved when the drive cable housing and the guide tubes are laid out in straight line. Control units fitted with odometer give an approximate indication of the source position, but is no substitute for proper use of a survey meter.

To return the source to the projector the crank is rotated in the 'RETRACT' direction (clockwise). The drive cable cannot be disconnected from the source assembly unless the source assembly is properly stored in the projector.
d. Exposure: When the source reaches the end stop at the radiographic focal position, an odometer will indicate (in feet and inches) the approximate distance travelled by the source (Fig. 5).

The systems are designed for safe and reliable operation provided that they are properly used and maintained.
Appendix B

OVEREXPOSURE INVESTIGATION REPORT

1. Name of Licensee:
2. Address:
3. Radioactive Material License No.:
4. Overexposed Personnel’s Information:
   a. Name:
   b. Designation:
   c. Date of Birth:
   d. Age:
   e. Sex:
   f. Functions/Duties in the company:

5. Monitoring period during which the incident occurred:
6. Amount of exposure obtained (film badge results):
7. Radiation sources in the facility:
   Type of source  Radioisotope  Activity  Reference
   (Indicate device and Date
   Serial No. of Source)
8. Radiation Monitoring Devices that were in use at the time of the incident.
   Type  Model No.  Serial No.  Calibration Factor  Date of latest calibration

9. Maximum Dose Reading and its specific location within the working area at the time of the incident:

10. Radiation source/Equipment being handled during the incident:

11. Prepare a sketch of the area or provide representative pictures of the location of the incident
    including monitoring results at the specific points. (Use extra sheets.)

12. Describe in detail the events during and after the exposure incident. If possible provide approximate
    time (duration) dose rates, most probable cause of overexposure, and pen dosimeter readings. (Use
    extra sheets.)

13. Exposure record of the exposed personnel for the past twelve (12) months period. Provide
    certifications if possible.

14. Immediate action done to mitigate adverse effect of accident (Provide certification issued by
    administering physician/clinic personnel.)

15. Corrective actions taken to prevent recurrence of the incident:

   Accomplished by: RHSO
   Date: 

   Concurred by: 
   Date: 
Table 1. Summary of Industrial Gamma Radiography Incidents in the Philippines, 1979 - 1993

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Date of Incident</th>
<th>Source Activity</th>
<th>Dose (Film Badge)</th>
<th>Nature of Incident</th>
<th>Probable Cause</th>
<th>Corrective Actions</th>
</tr>
</thead>
</table>
| 1        | Oct. 1979        | 8 Ci Ir-192     |                   | The pigtail assembly of the camera was disconnected from the drive cable & got trapped inside the guide tube. Retrieval of the source led to the exposure of personnel. | a. Improper maintenance  
b. Violation of emergency & operating procedures | a) Proper maintenance & inspection of equipment  
b) Re-training of personnel |
| 2        | Aug. 1982        | 53 Ci Ir-192    | 550mR             | The male connector of the drive cable was broken & the source pigtail assembly was left inside the guide tube. | a. Component malfunction  
b. Improper maintenance | a) Proper maintenance & inspection of equipment |
| 3        | June 1983        | 88 Ci Ir-192    | 185mR             | The male connector of the drive cable was broken & the source pigtail assembly was left inside the guide tube. The guide tube containing the source pigtail was transferred to another place. The retrieval were carried out the following day after some occupants of the adjacent rooms was alarmed of high radiation dose rate in their area. | a. Poor maintenance & inspection  
b. Improper handling of incident | a) Proper maintenance & inspection of equipment  
b) Prompt action during emergencies |
<p>| 4        | Nov. 1983        | 4.4 Ci Ir-192   | 20mR 35mR         | During radiography operation, the radiation monitoring showed that the survey meter reading is way beyond the normal reading when the source is in shielded position. The personnel involved was alarmed &amp; immediately searched for the cause of the high radiation reading. It was found out that the source was disconnected from the drive cable. The retrieval operation was carried out by PNRI personnel upon the request of the company. | a. Poor maintenance &amp; inspection | a) Proper maintenance &amp; inspection of equipment |</p>
<table>
<thead>
<tr>
<th>Date</th>
<th>Activity</th>
<th>Source/Activity Details</th>
<th>Cause</th>
<th>Measure</th>
</tr>
</thead>
</table>
| Feb. 1984  |                  | The radiographers left the camera at the basement of the die sulphur diesel reactor. After 2 days of no work, the radiographer returned to find that the source/camera is missing. The source/camera was never recovered. | a. Improper storage  
b. Violation of operating procedures  
c. Violation of incident reporting | a) Inventory of radioactive materials  
b) Proper storage of radioactive materials  
c) Prompt reporting |
| Sept. 1985 |                  | The source/camera was discovered missing from its permanent storage pit on 24 Sept. 1985. The incident was reported the following day. The source was recovered on Oct. 7, 1985. | a. Theft  
b. Poor storage of facility | a) Adequate safeguarding measures  
b) Adequate storage facility |
| July 1987  |                  | The male connector of the drive cable was broken & the source pigtail assembly was left inside the guide tube. Retrieval of the source led to the overexposure of personnel. | a. Improper maintenance  
b. Component malfunction due to poor inspection  
c. Violation of emergency procedures | a) Proper maintenance & inspection of equipment  
b) Re-training of personnel on emergency procedures |
| Sept. 1989 |                  | Four (4) personnel were exposed to gamma radiation when the source pigtail assembly was disconnected from the drive cable. One (1) personnel retrieved the source using his bare hand. | a. Violation of operating & emergency procedures  
b. Improper maintenance  
c. Improper handling | a) Re-training of personnel  
b) Proper maintenance & inspection of equipment  
c) Re-training in radiation safety |
| Sept. 1989 |                  | A radiographer’s assistant was exposed to radiation while setting the film at the other side of the boiler. The transmission of the radio communicator was obstructed by the boiler. The incident was discovered only after the film badge was processed. | a. Violation of operating & emergency procedures  
b. No proper radiation survey | a) Re-training of personnel  
b) Proper radiation area monitoring |
<table>
<thead>
<tr>
<th>Date</th>
<th>Date</th>
<th>Description</th>
<th>Event Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Feb. 1989</td>
<td>54 Ci Ir-192</td>
<td>100 mR</td>
<td>The source guide tube was disconnected from the camera while cranking out the source. The personnel involved retrieved the source using his bare hands.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>a. Improper connection of guide tube</td>
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<td>b. Violation of emergency procedure</td>
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<td></td>
<td></td>
<td></td>
<td>c. Improper handling of RAM</td>
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<tr>
<td>11 Feb. 1990</td>
<td>76.36 Ci Ir-192</td>
<td>1.13 rem, 970 mR, 530 mR, 400 mR</td>
<td>During radiography operation, the radiographer's assistant, while doing the 2nd to the last exposure noticed that his pocket dosimeter was off-scaled. His other two (2) team members also got high readings.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>a. No proper radiation survey</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>b. Violation of operating procedures</td>
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<tr>
<td>12 March 1990</td>
<td>31.96 Ci Ir-192</td>
<td>485 mR</td>
<td>The pocket dosimeter of one of the radiographers read 50 mR before the start of the radiography operation. The dosimeter was not reset to zero. After the work was completed, the radiographer noticed that his pocket dosimeter was off-scale. The two (2) personnel got high readings.</td>
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<td></td>
<td>a. No proper radiation survey</td>
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<td>b. Violation of operating procedures</td>
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<tr>
<td>13 April 1990</td>
<td>30 Ci Ir-192</td>
<td>945 mR</td>
<td>The pocket dosimeter of one of the radiographers read 10 mR before the start of the radiography operation. After the 7th exposure the radiographer noticed that his pocket dosimeter was off-scale.</td>
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<td></td>
<td></td>
<td></td>
<td>a. No proper radiation survey</td>
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<tr>
<td></td>
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<td></td>
<td>b. Violation of operating procedures</td>
</tr>
<tr>
<td>14 April 1991</td>
<td>2.4 Ci Ir-192</td>
<td></td>
<td>The incident happened on April 1, 1991 when the taxi sped off with the source/camera while the workers were unloading the other gadgets. The radioactive material/equipment involved was borrowed from other licensed radiography company without the authorization from the Institute. The source/camera was returned to PNRI after a high media campaign.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>a. Violation of operating procedures, particularly the transport procedure</td>
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<td></td>
<td></td>
<td></td>
<td>b. Unauthorized lease of source</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>a) Re-training in radiation safety</td>
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<tr>
<td>Date</td>
<td>Activity</td>
<td>Count</td>
<td>Dose</td>
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<tr>
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<tr>
<td>April 1991</td>
<td>15 April 1991</td>
<td>20 Ci</td>
<td>Ir-192</td>
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<td></td>
<td></td>
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<tr>
<td>April 1992</td>
<td>16 April 1992</td>
<td>18.3 Ci</td>
<td>Ir-192</td>
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<tr>
<td>June 1992</td>
<td>17 June 1992</td>
<td>70 Ci</td>
<td>Ir-192</td>
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<tr>
<td>Jan. 1993</td>
<td>18 Jan. 1993</td>
<td>19 Ci</td>
<td>Ir-192</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>April 1993</td>
<td>19 April 1993</td>
<td>17 Ci</td>
<td>Ir-192</td>
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</table>
1.39 rem & 630 mR for each personnel involved in the retrieval operation.

The radiography trainee retracted the source & immediately disconnected the guide tube from the camera without using the survey meter. The trainee noticed that the source was protruding the camera/shielding approximately 1/2" from the exit port. The result of the film badge when processed & evaluated was nil. However, calculated absorbed doses in his hand & head showed 993 rem & 270 mR, respectively.

20 Dec. 1993 11.0 Ci Ir-192

a. Violation of operating procedures
b. Unauthorized handling of radiographic equipment by trainee
a) Re-training of personnel in RT techniques & radiation safety
b) Close supervision of trainee by radiographer
RADIOLOGICAL INCIDENTS IN INDUSTRIAL GAMMA RADIOGRAPHY IN THE PHILIPPINES, 1979-1993