Report on the Questionnaires on Occupational Exposure in Industrial Radiography

Working Group on Industrial Radiography (WGIR)

Information System on Occupational Exposure in Medicine, Industry and Research (ISEMIR)

Working material

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EXECUTIVE SUMMARY

As part of the Information System on Occupational Exposure in Medicine, Industry and Research (ISEMIR) project, the Working Group on occupational exposures and radiation protection of personnel in industrial radiography (WGIR) was formed in 2010 to undertake 3 years of activity focussed on improving the implementation of occupational radiation protection in industrial radiography (IR).

One of the first tasks of the WGIR was to perform a survey to gain insight into occupational radiation protection in IR around the world. Three different questionnaires were distributed to: individual industrial radiographers (operators), non-destructive testing (NDT) companies, and national or state radiation protection regulatory bodies. The questionnaires were distributed widely over an approximate one year period (mid-2010 to mid-2011), primarily using industry and NDT society contacts of WGIR members and using IAEA contacts with regulatory bodies.

Responses were received from: 432 industrial radiographers from 31 countries and employed by approximately 150 different NDT companies; 95 NDT companies from 29 countries; and 59 regulatory bodies.

Because of the nature of the distribution of the questionnaires to individual industrial radiographers and to NDT companies, it is likely that those approached represent the better end of the practice spectrum. Hence, it is recognised that the survey results cannot purport to be truly representative of the worldwide practice of industrial radiography and all results must be interpreted with this caution. Further, many of the questions involved a radiographer or a company assessing their own habits or performance, and hence are subject to distortions of perception versus reality, thus placing a further caveat on those results. The distribution of the regulatory body questionnaire was systematic – contact was attempted for all IAEA Member States. Notwithstanding the above caveats, useful insight into current radiation protection practice in industrial radiography was gained.

The need for radiation protection training in industrial radiography appears to be well accepted, with a reported high prevalence of initial theoretical and practical training. The use of refresher radiation protection training could, however, be improved – only two-thirds of regulatory bodies required such training.

Accidents, near misses and deviations from normal practice are widely recognized as being a characteristic of industrial radiography, and the results of this survey provide such confirmation – they do occur. It is likely that the derived rates of occurrence from the survey (e.g. 0.04 accidents per radiographer per 5 years) are an underestimate. The rates estimated from the radiographer data were higher than the estimates based on company data, suggesting that what happens "in the field" may not necessarily be reflected in the company reporting, and is even less likely to be reflected in the regulatory body reporting. Means for minimizing the likelihood of incidents remains a priority.

The survey showed that the use of collimators in gamma radiography and diaphragms in X-ray radiography, and the general use of survey meters, whilst high, was not as high as it should be. Further, about one-half of the radiographers and the NDT companies reported that on-site radiography was being performed without the presence of the radiation protection officer (RPO), and hence without the benefit of the specific radiation protection expertise.

Almost all regulatory bodies required the use of a warning system to prevent entry to the radiography site. The results of the survey suggest that communication between the NDT company and the client (who is receiving the on-site radiography services) is less than desirable. Less than half of the regulatory bodies require the client to inform the NDT company about conditions on the site that might affect the safety of other workers on site. This was then reflected in practice where 30% of NDT

companies reported that their clients were not always providing information about other interfering activities on site.

The majority of regulatory bodies had regulatory performance requirements for the safety of sources and exposure devices, and for periodic inspections/tests and maintenance to verify compliance with those standards. Almost all NDT companies reported performing preventative maintenance.

High percentages of both the NDT companies and the regulatory bodies were performing inspections of the radiographers at work. Both announced and unannounced inspections were being used. The results suggest that a radiographer could expect to be inspected at least twice a year by their NDT company and about once or twice a year by the regulatory body. The five most common shortcomings for the NDT company inspections were: no proper use of collimators, dose rate at the boundary of the work site not within limits set, no proper use of survey meters, no pre-operation specific equipment checks being performed, and poor operator knowledge of procedures. For the regulatory body inspections, the five most common shortcomings were: no proper use of survey meters, no proper warning system to prevent entry to the work site, poor emergency preparedness, no proper use of alarm systems, and dose rate at the boundary of the work site not within limits set.

Radiation sources used for industrial radiography purposes have high radiation outputs and are potentially very hazardous. Incidents do occur and it is essential that systems are in place for emergency preparedness and response, in particular an emergency plan.

Almost all regulatory bodies stated that they require NDT companies to have an emergency plan; 95% of NDT companies stated that they had an emergency plan; and over 90% of radiographers stated that their NDT company had an emergency plan for site radiography. The role of the radiographer in an emergency is crucial. Almost 90% of radiographers reported that they had received training for the roles and responsibilities of radiographers in the emergency plan; and, over 90% of NDT companies stated that their emergency plan had been discussed with their radiographers and over 80% of NDT companies reported that they provided specific training on emergency preparedness and response. The last figure reflects the practice that some countries have requirements to use specialist persons in emergency roles, and hence specific training for radiographers in this role is not seen as appropriate.

Reported individual monitoring data for 2009 from the radiographer questionnaire and the regulatory body questionnaire gave average annual effective dose estimates for industrial radiographers of 3.4 and 2.9 mSv, respectively. Approximately 2% of industrial radiographers received an annual effective dose in 2009 that exceeded the dose limit of 20 mSv. From the data submitted, the estimate (at the 95% level) of the mean occupational effective dose per exposure was 4.8 ± 2.3 µSv per exposure. There was no correlation between the annual effective dose in 2009 and the radiographers' radiographic workload in 2009, emphasizing that occupational radiation protection in industrial radiography is not being effectively optimized.

In summary, the survey results indicate that there is a need for improved implementation of the radiation protection principle of optimization of protection and safety.

To this end, the results from the survey are being used to design the ISEMIR international database that will be used by end-users to improve their implementation of optimization in occupational radiation protection in industrial radiography, and to develop a "roadmap" tool that enables NDT companies to assess their own performance in radiation protection against accepted practice.

The WGIR would like to thank sincerely the many individual industrial radiographers, NDT company personnel, and regulatory body staff who responded to the questionnaires. Without their time and input this survey would not have been possible.

1. INTRODUCTION

In 2009, the IAEA launched the Information System on Occupational Exposure in Medicine, Industry and Research (ISEMIR) – a project aimed at improving occupational radiation protection in those areas of radiation use in medicine, industry and research where non-trivial occupational exposures occur. The first task of the Advisory Group of ISEMIR was to identify such areas of radiation use, and to form working groups to address these areas. Industrial radiography was one of the areas identified, and in January 2010 the Working Group on Industrial Radiography (WGIR) was formed. The membership of WGIR is given in Appendix V, and is comprised of professionals with experience of working for non-destructive testing (NDT) companies, client companies, NDT societies, technical service organizations, including education, training and inspection, and regulatory bodies.

The mandate for WGIR included: to gain a world-wide overview of occupational exposures and radiation protection of personnel in industrial radiography; to identify both good practices and shortcomings, and hence define actions to improve occupational radiation protection; and to set up a system for regularly collecting and analysing occupational doses for individuals in industrial radiography and for dissemination of this information to improve occupational radiation protection.

Hence, as part of its initial actions, WGIR sought to gain insight into occupational radiation protection in industrial radiography world-wide using questionnaires. This report presents the results from this survey, which included responses from 432 industrial radiographers, 95 NDT companies, and 59 regulatory bodies.

2. METHOD

Three questionnaires were developed – one addressed to individual industrial radiographers, another to NDT companies, and a third to national or state radiation protection regulatory bodies. Each questionnaire addressed the topics of training in radiation protection; incidents; safety of the radiographer, the public and sources; inspections; emergency plans; and individual monitoring. The questionnaire for individual industrial radiographers was comprised of 14 main questions. The NDT company questionnaire and the regulatory body questionnaire were more complex, comprising 31 and 29 main questions, respectively. To help elicit a wider response, both the radiographer questionnaire and the NDT company questionnaire were available in several languages – Chinese, English, French, German, Portuguese, Russian and Spanish, with the addition of Dutch for the radiographer questionnaire. The Regulatory Body questionnaire was in English only. The English versions of the questionnaires are reproduced in Appendix IV.

The questionnaires were distributed widely over an approximate one year period (mid-2010 to mid-2011), primarily using the industry and NDT society contacts of WGIR members and using IAEA contacts with regulatory bodies. Responses from radiographers were anonymous unless the responder wished to be identified.

3. RESULTS

The survey produced a large amount of information, and this section will present the main findings only from the three questionnaires, while the detailed results (including regional analysis) in the form of tables, figures and notes are given in Appendices I-III. In many of the responses to the questionnaires, not all questions were answered. In calculating the percentages given in this section, “no reply” answers were excluded from the totals for that question, unless otherwise stated. For questions where the questionnaire instruction was to “*tick all options applicable*”, then a “no reply” for a given option was interpreted as meaning that that option was not applicable, and hence equivalent to being a “no”, and these were included in the totals for that question.

3.1. CAVEATS

Because of the nature of the distribution of the questionnaires to individual industrial radiographers and to NDT companies, it is likely that those approached represent the better end of the practice spectrum. In the case of the industrial radiographer survey there were regional biases, with two thirds of responses coming from Europe and North America. Further, one quarter of all industrial radiographer responders were the only responder from that NDT company, and hence were likely to have been the radiation protection officer (RPO), or at least a person with an interest in radiation protection. Hence, it is recognised that the survey results cannot purport to be truly representative of the worldwide practice of industrial radiography and all results must be interpreted with this caution. Further, many of the questions involved a radiographer or a company assessing their own habits or performance, and hence are subject to distortions of perception versus reality, thus placing a further caveat on those results.

The distribution of the regulatory body questionnaire was systematic – contact was attempted for all IAEA Member States. However, not all regulatory bodies responded, and some of those not responding were regulatory bodies of large countries.

Notwithstanding the above caveats, some useful insight into current radiation protection practice in industrial radiography was gained, as summarized below. Further details are given in Appendices I to V.

3.2. NUMBER OF RESPONSES

Individual industrial radiographer operators:

- 432 responses from industrial radiography operators, from approximately 150 different NDT companies, and 31 different countries.
- Nearly 200 radiographers provided their approximate annual workload (number of exposures) in 2009, with an average of just under 3000 exposures and a median of 1000.
- In 2009, approximately three-quarters of the radiographers were using Ir-192 sources, with a mean and median activity of about 40 Ci; about one-third were using Se-75 sources, with a mean and median activity of about 40 Ci; about 10% were using Co-60 sources, with a mean and median activity of about 40 Ci; and about one-half were using X-ray equipment, with a mean kVp of 230 kV.

NDT Companies:

- 95 responses from NDT companies performing industrial radiography, from 29 different countries.
    - Of the 95 NDT companies, 73 performed both gamma and X-ray radiography, 14 performed gamma radiography only, and 8 X-ray radiography only.
    - 82 NDT companies gave information on their number of radiographers:
        - The mean number of fulltime radiographers per NDT company was 39, with a median of 17. One-half of NDT companies employed less than 20 fulltime radiographers. Eight employed more than 100 fulltime radiographers.
        - Few NDT companies (14 out of 81) stated that they employed part-time radiographers.
    - 74 NDT companies gave further information on their radiographers:
        - On average, three-quarters of the radiographers in a company were involved in site radiography, and half were performing site radiography fulltime.
        - On average, 60% of the radiographers in a company were using both gamma sources and X-rays, 25% gamma sources only, and 15% X-rays only.
    - Almost all NDT companies (97%, 91 out of 94) stated that they have an RPO or radiation protection expert (RPE) included in their organization.
        - Of these, the majority (88%, 78 out of 89) report directly to the managing director.

Regulatory bodies:

- 59 responses from regulatory bodies (55 national regulatory bodies and 4 state regulatory bodies[1]) from 55 countries. Contact was attempted with 142 radiation protection regulatory bodies from 133 countries, giving a participation rate of about 40%. The responding regulatory bodies have jurisdiction over countries whose summed population is also about 40% of the world's total population.

3.3. RADIATION PROTECTION TRAINING AND QUALIFICATIONS OF INDUSTRIAL RADIOGRAPHERS

Individual industrial radiographers:

- 30% of radiographers (121 out of 408) had level 1 as their highest level of NDT training; 54% (221 out of 408) had level 2; and 16% (66 out of 408) had level 3[2].
- The majority of radiographers stated that radiation protection training was included in their NDT training on radiographic testing – 89% (286 out of 321) for level 1; 86% (249 out of 289) for level 2; and 53% (47 out of 88) for level 3.

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[1] Some Member States have a federal system of government, where each "state" within the country has jurisdiction over the use of radiation in industrial radiography.

[2] NDT training is typically structured around three levels of training, with level 1 being the lowest level of training and level 3 the highest. Qualification and certification of NDT personnel in accordance with International Standards such as ISO 9712 (Non-destructive testing – Qualification and certification of personnel) and aligned standards helps to ensure that people are competent, and assists global safety standards.

- 85% of radiographers (364 out of 427) stated that they had received separate radiation protection training and, of these, most (87%, 312 out of 358) stated that they had a formal qualification in radiation protection.
- Only 8 out of 432 responding radiographers (2%) appeared to have not had radiation protection training, either as part of the NDT training or as separate training.
- 89% of radiographers (375 out of 422) stated that procedures for emergencies were included in the radiation protection training, and of these:
  - Two-thirds (247 out of 369) said that the training included practical exercises for creating a safe situation until the source is able to be recovered;
  - 57% (195 out of 342) said that the training included practical exercises for source recovery.
- Three-quarters of radiographers (302 out of 402) stated that they were not allowed to perform a source recovery on their own without first contacting a specialized source recovery person.
- Almost all radiographers (96%, 410 out of 425) felt sufficiently well qualified and trained to be able to work safely and reliably.
- 10% of radiographers (40 out of 417) stated that they did not feel well prepared for an emergency situation. About one-half of these had had no training in creating a safe situation or in source recovery, and most were not allowed to perform source recovery.

NDT companies:

- Almost all NDT companies (98%, 93 out of 95) stated that they provide or facilitate radiation protection training for their radiographers. Of these NDT companies:
  - 72% provide within the company initial theoretical radiation protection training, with a mean duration of 21 hours.
  - 69% provide within the company initial practical radiation protection training, with a mean duration of 21 hours.
  - 66% provide within the company refresher theoretical radiation protection training, with a mean duration of 10 hours, and a mean interval between training of 13 months.
  - 49% provide within the company refresher practical radiation protection training, with a mean duration of 9 hours, and a mean interval between training of 10 months.
  - 65% provide outside the company initial theoretical radiation protection training, with a mean duration of 32 hours.
  - 47% provide outside the company initial practical radiation protection training, with a mean duration of 23 hours.
  - 51% provide outside the company refresher theoretical radiation protection training, with a mean duration of 15 hours, and a mean interval between training of 34 months.
  - 31% provide outside the company refresher practical radiation protection training, with a mean duration of 16 hours, and a mean interval between training of 33 months.
- Combining the responses for training that occurs within and outside the company gave:
  - Nearly all NDT companies (96%, 89 out of 93) provided initial theoretical radiation protection training, either inside or outside the company or both. Only 4 NDT companies responded that they provided neither.
    - Mean initial radiation protection training (theory) – 37 hours.

  - Most NDT companies (82%, 76 out of 93) provided initial practical radiation protection training, either inside or outside the company or both. 17 NDT companies responded that they provided neither.
    - Mean initial radiation protection training (practical) – 30 hours.
  - Most NDT companies (83%, 77 out of 93) provided refresher theoretical radiation protection training, either inside or outside the company or both. 16 NDT companies responded that they provided neither.
    - Mean refresher radiation protection training per 5 years (theory) – 90 hours.
  - Just over half the NDT companies (58%, 54 out of 93) provided refresher practical radiation protection training, either inside or outside the company or both. 39 NDT companies responded that they provided neither.
    - Mean refresher radiation protection training per 5 years (practical) – 90 hours.
- Just over half of NDT companies (49 out of 92) stated that they provide different radiation protection training for gamma sources and for X-Ray sources.
- With respect to training on specific aspects of emergency preparedness and response:
  - Almost all (90 out of 92) stated that the training included emergency procedures.
  - 84% (77 out of 92) stated that the training included practical exercises for creating a safe situation.
  - 66% (60 out of 91) stated that the training included practical exercises for source recovery. There appeared to be a regional difference between Asia-Pacific (84%) and Latin America (74%), and the remaining regions – Africa (50%), North America (50%) and Europe (46%).
- The majority of NDT companies stated that radiation protection training was included as part of NDT training in radiographic testing in their country – 86% for NDT level 1, 75% for NDT level 2, and 49% for NDT level 3. When results for the same country were combined, and contradictory results excluded, the percentages increased to 100% for level 1, 94% for level 2, and 57% for level 3.
- 92% of NDT companies stated that they provide radiation protection training in addition to that contained in the NDT training.

Regulatory bodies (RBs):

- Almost all regulatory bodies (58 out of 59) stated that they require a person wishing to perform on-site radiography to have had radiation protection training to an acceptable level.
  - Of these, about 70% (35 out of 50) considered the radiation protection training given as part of the NDT-training on radiographic testing was acceptable;
  - About 80% (43 out of 53) considered that radiation protection training given as a separate training course was acceptable; and
  - About 40% (22 out of 56) considered both as being acceptable.
- Over 80% of the RBs (43 out of 53) stated that they had the same radiation protection training requirements for using gamma sources as for using X-ray machines.
- Nearly 90% of the RBs (51 out of 58) stated that they required the radiation protection training to include both theoretical and practical training.
- 70% of the RBs (41 out of 57) stated that the radiation protection training had to include practical exercises for creating a safe situation in an emergency until the source is able to be recovered.

- A smaller percentage (63%, 34 out of 54) stated that the radiation protection training had to include practical exercises for source recovery in an emergency. This lower figure reflects that in many countries, source recovery is restricted to specialised persons.
- The majority of RBs (90%, 50 out 57) stated that they required the passing of an examination at the end of the radiation protection training, with:
  - 44 % requiring a theory only examination; and
  - 56% requiring the examination to be both theoretical and practical.
- Separate radiation protection training was allowed to be provided by:
  - the RB in 42% (18 out of 43) of responses;
  - educational institutes in 56% of responses (24 out of 43);
  - NDT companies in 44% of responses (19 out of 43); and
  - private radiation protection consultants in 47% of responses (20 out of 43).
- 70% of RBs (41 out of 59) stated that they required refresher training in radiation protection for persons performing on-site radiography.
  - For these RBs, the average interval between refresher courses was 4 years; and
  - Over one-half of the RBs (21 out of 38) required an examination as part of the refresher training.

3.3.1. Radiation Protection Officers (RPOs):

- Almost all regulatory bodies (57 out of 59) stated that they require a person wishing to act as an RPO for a company that performs on-site radiography to have had radiation protection training to an acceptable level. Of these:
  - Nearly 70% (39 out of 56) stated that the RB would require a higher level of radiation protection training for the RPO than that for an operator; and
  - About 80% (42 out of 52) stated that there was an examination.
- Just over one-half of the radiographers (232 out of 415) stated that there is always a qualified radiation safety expert (RPO or RPE) on the work site, supervising the job, when on-site radiography is being performed; and a further one-third said that an RPO was sometimes present. Of the 26 “never” responses, almost all were radiographers with either level 2 or level 3 NDT training.

3.4. INCIDENTS (DEVIATIONS, NEAR MISSES AND ACCIDENTS)

Individual industrial radiographers:

- 20% of radiographers (83 out of 422) stated that they had had an incident (accident, near miss or deviation) in the last 5 years.
  - A total of 229 deviations were said to have occurred from 409 responses, giving an average of 0.6 deviations per radiographer per 5 years.
  - A total of 41 near misses were said to have occurred from 409 responses, giving an average of 0.1 near misses per radiographer per 5 years.
  - A total of 16 accidents were said to have occurred from 409 responses, giving an average of 0.04 accidents per radiographer per 5 years.
- Most radiographers (87%, 71 out of 82) who had had incidents in the last 5 years said that they always reported them to their NDT company.
- Less than half the radiographers who had reported incidents believed that their company had, in turn, reported these to the regulatory body; 20% believed the company did not report the incidents; and one-third did not know.

NDT companies:

- 40% of NDT companies (35 out of 87) stated that they had had an incident (accident, near miss or deviation) in the last 5 years.
    - 85% (72 out of 85) reported that they had had no accidents in the last 5 years. A total of 93 accidents were said to have occurred, giving an average of 1.1 accidents per NDT company per 5 years.
    - 70% (59 out of 84) reported that they had had no near misses in the last 5 years. A total of 150 near misses were said to have occurred, giving an average of 1.8 near misses per NDT company per 5 years.
    - 82% (64 out of 78) reported that they had had no deviations in the last 5 years. A total of 140 deviations were said to have occurred, giving an average of 1.8 deviations per NDT company per 5 years.
- Using data on the number of radiographers in a given NDT company, the following event frequencies were derived:
    - An average of 0.03 accidents per radiographer per 5 years.
    - An average of 0.05 near misses per radiographer per 5 years.
    - An average of 0.05 deviations per radiographer per 5 years.
- Another estimate of the occurrence of incidents in an NDT company was obtained by scaling the results from the radiographer questionnaires on the basis of the number of number of radiographers who completed the questionnaire versus the total number of radiographers for that NDT company, obtained from the NDT company questionnaires This gave:
    - An average of 4.0 accidents per NDT company per 5 years.
    - An average of 6.2 near misses per NDT company per 5 years.
    - An average of 29.3 deviations from normal per NDT company per 5 years.
- With respect to reporting radiation incidents to the regulatory body:
    - All accidents with individual exposures higher than the annual dose limits (11 out of 11) were said to have been reported.
    - 70% of accidents with elevated individual exposures lower than the annual dose limits (57 out of 82) were said to have been reported.
    - 24% of near misses (36 out of 150) were said to have been reported.
    - 15% of other deviations from normal (21 out of 140) were said to have been reported.
    - Very few NDT companies (4%, 1 out of 24) stated that their regulatory body had, in turn, reported the radiation incidents to the IAEA.
- The main sources of information for an NDT company about abnormal individual exposure of its radiographers were:
    - From the dosimetry service providers, third party, regulatory body or company, based on the readings from passive dosimeters) – 91% (85 out of 93); and
    - Directly from the radiographers via their active dosimeters – 58% (55 out of 95).
- The main means for NDT companies to share information, within the company, about radiation incidents was safety meetings (86%, 82 out of 95). Email was the next most common means (40%, 38 out of 95). Two-thirds of NDT companies (58 out of 91) used two or more methods. Four companies did not select any options, implying that information on incidents was not shared.
- The main means for NDT companies to share information about radiation incidents with other organizations was industry meetings (33%, 31 out of 95). Email was the next most common means (27%, 26 out of 95). 23% (22 out of 95) stated that they did not share

information on incidents with other organizations, and a further 14 companies did not select any options. This would suggest that 38% (36 out of 95) do not share information on incidents with other organizations.

Regulatory bodies:

- Over 90% of regulatory bodies (55 out of 59) stated that there were requirements for licensees to report radiation incidents in industrial radiography to the regulatory body. The main criteria for reporting were: a lost or stolen source; a stuck source or equipment malfunction with implications for safety; or, an event that caused, or could have caused, significant exposure to workers or the public.
- Over 80% of regulatory bodies provided statistics on the number of notified events in the last 5 years, as follows:
    - Accidents with elevated individual exposures greater than the annual dose limit:
        - 50 regulatory bodies replied:
            - 36 regulatory bodies reported zero notifications.
            - A total of 34 accidents were notified, giving an average of 0.7 such accidents per jurisdiction per 5 years.
    - Accidents with elevated individual exposures less than the annual dose limit:
        - 48 regulatory bodies replied:
            - 29 regulatory bodies reported zero notifications.
            - A total of 181 accidents were notified, giving an average of nearly 4 such accidents per jurisdiction per 5 years.
    - Near misses with the potential for elevated individual exposures greater than the annual dose limit:
        - 46 regulatory bodies replied:
            - 37 regulatory bodies reported zero notifications.
            - A total of 22 near misses were notified, giving an average of 0.5 such events per jurisdiction per 5 years.
    - Near misses with the potential for elevated individual exposures less than the annual dose limit:
        - 46 regulatory bodies replied:
            - 35 regulatory bodies reported zero notifications.
            - A total of 46 near misses were notified, giving an average of 1 such event per jurisdiction per 5 years.
    - Notified deviations from normal operations:
        - 44 regulatory bodies replied:
            - 28 regulatory bodies reported zero notifications.
            - A total of 181 deviations were notified, giving an average of 4.1 such events per jurisdiction per 5 years.
- Two-thirds of regulatory bodies (40 out of 58) stated that they maintain a radiation incident database for their jurisdiction. Of these:
    - About 70% (23 out of 34) analyse the database regularly to determine if there are common factors in the incidents.
    - Two-thirds (23 out of 35) stated that they used the INES system to classify the severity of incidents.
- Only about one-half of regulatory bodies (27 out of 55) stated that they have an established system for sharing lessons learned from reported incidents. Of these, almost all (24 out of 27) disseminated information to the operating NDT companies in their

jurisdiction, but fewer than half (10 out of 27) disseminated information to other regulatory bodies.
  - From the 17 regulatory bodies providing data on the number of disseminations, there were a total of 18 instances of disseminating information to NDT companies in the last 5 years, giving an average of approximately 1 action of dissemination per jurisdiction per 5 years.
  - One regulatory body reported a high number (86) of disseminations to other regulatory bodies over the last 5 years. The next highest number was 5.
- About 30% of regulatory bodies (16 out of 50) stated that they had reported an industrial radiography incident to the IAEA in the last 5 years.

3.5. SYSTEMS AND PROCEDURES TO ENSURE PROTECTION AND SAFETY IN INDUSTRIAL RADIOGRAPHY

3.5.1. Safety of the radiographer

Individual industrial radiographers:

- Nearly 90% of radiographers (373 out of 418) stated that they always check for the presence of the source in the exposure device <u>before</u> taking the device from the store, and 95% (396 out of 418) always check <u>after</u> the NDT test.
- 80% of radiographers (338 out of 418) stated that they always use collimators when performing gamma radiography. A further 18% (77 out of 418) stated that they sometimes use collimators. Only 3 out of 418 said they never used collimators.
- Almost one-half of radiographers (181 out of 377) stated that they always use diaphragms/collimators when performing X-ray radiography. A further 35% (133 out of 377) stated that they sometimes use diaphragms/collimators. About 10% stated that they never use diaphragms/collimators.
- 77% of radiographers (320 out of 416) stated that they discussed radiation protection issues or their occupational doses with their RPO, and the mean number of discussions per year was 6. 20% of radiographers (90 out of 416) stated that they did not have such discussions.

NDT companies:

- All NDT companies stated that they provide their industrial radiographers with at least one form of dosimeter. 88% (84 out of 95) of companies stated that they provide their industrial radiographers with passive dosimeters, and 93% (82 out of 95) that they provide active dosimeters. 76% (72 out of 95) of companies stated that they provide both forms.
- Of those 82 NDT companies providing active dosimeters, the percentage that provided active dosimeters with the following features were:
  - Audible alarm – 85% (70 out of 82);
  - Visual alarm – 52% (43 out of 82);
  - Vibrating alarm – 5% (4 out of 82).
- All NDT companies stated that they keep records of occupational doses received by their radiographers. Almost all companies (90 out 93) stated that they inform their radiographers of their personal doses.

- 62% of NDT companies (58 out of 94) stated that they have established investigation levels for personal doses. A larger percentage (82%, 72 out of 88) stated that the regulatory body has established investigation levels for personal doses.
  - For those NDT companies that had an investigation level, 79 gave data on the number of investigations in the last 5 years. Nearly 50% (37 out of 79) stated that they had performed no investigations. A total of just over 750 investigations were said to have taken place, giving an average of nearly 10 investigations per NDT company per 5 years. This corresponds to an average of about 0.2 investigations per radiographer per 5 years.
- A high percentage of NDT companies (91%, 86 out of 94) stated that they provided survey meters.
- The majority of NDT companies (68%, 64 out of 94) stated that they provided area monitors. Most area monitors had visual alarms (46 out of 55) and audible alarms (49 out of 60).
- Almost all NDT companies (93%, 78 out of 84) stated that they require their radiographers to use collimators with gamma radiography. This is a little higher than the radiographer responses for the same companies, where about 80% said they always used collimators and about 20% used them sometimes.
- The majority of NDT companies (78%, 61 out of 79) stated that they require their radiographers to use collimators with X-ray radiography. Radiographer responses for 45 of these companies indicated that some radiographers in 8 of the companies never used collimators, despite the company requirement.

Regulatory bodies:

- Excluding 3 “no replies”, all regulatory bodies stated that they require industrial radiographers to use passive dosimeters. 80% (45 out of 56) also required industrial radiographers to have active dosimeters.
- Of those regulatory bodies requiring active dosimeters, the following features were required:
  - Measurement of integrated dose – 64% (27 out of 42);
  - Audible alarm – over 90% (41 out of 44);
  - Visual alarm – 63% (25 out of 40);
  - Vibrating alarm – 24% (9 out of 38).
- Reporting of monitored doses of industrial radiographers:
  - 80% of the regulatory bodies (44 out of 54) stated that the radiographers had to be informed about their doses, with a median value of 12 times per year;
  - 90% of the regulatory bodies (53 out of 58) stated that the NDT company or employer had to be informed about the industrial radiographer doses, with a median value of 12 times per year;
  - 70% of the regulatory bodies (38 out of 53) stated that the regulatory body had to be informed about the industrial radiographer doses, with a median value of 4 times per year; and
  - 70% of the regulatory bodies (36 out of 49) stated that the national personal dose database had to be informed about the industrial radiographer doses, with a median value of 12 times per year.
- Almost all regulatory bodies (52 out of 55) required the industrial radiographer to always have a functioning and calibrated survey meter with them.

– 90% of regulatory bodies (52 out of 57) stated that they require the NDT company to employ an RPO or RPE. Of these, 80% (40 out of 51) require that the RPO or RPE reports directly to the Managing Director, or equivalent, of the NDT company.

3.5.2. Safety of the public

NDT companies:

– 70 NDT companies provided data on the dose rate at which a warning system is required to be set up. The mean dose rate was 13 µSv per hour, with a median of 7.5 µSv per hour and an inter-quartile range of 2.5–20 µSv per hour.
– Rope or ribbon was used in the warning system in the majority of cases (89%, 84 out 94), plus a high usage of signage – 76% (71 out of 94) for passive warning signs and 71% (67 out of 94) for active warning signs.
– 58% of NDT companies (53 out of 91) stated that they had determined the more common causes for unauthorized persons to trespass past the warning system. The most common stated causes were wilful violation (84%) and the warning system not being understood (60%), with incorrect setting up of the warning system also being indicated (20%).
– 72% of NDT companies (67 out of 93) require their radiographers to <u>always</u> announce or warn whenever a radiographic exposure is made. 13% of companies (12 out of 93) stated that they did not require such announcements or warnings. Where an announcement or warning was required, a visible alarm (such as flashing lights) was the most common method (86%), followed by an announcement via a public address system (51%), and an audible alarm (44%). Often, more than one method was used.
– When NDT companies are providing radiography services in an industrial plant:
    - o The majority of NDT companies (71%, 60 out of 84) reported that the client was <u>always</u> providing information about other interfering activities on site.
    - o Less than half the NDT companies (45%, 37 out of 83) stated that the client <u>always</u> provided a plan of the installation. On the other hand, few companies (7%, 6 out of 83) stated that they were <u>never</u> provided with plans.
    - o About half the companies (53%, 45 out of 85) said that the client <u>always</u> had a “permit to work” system.
    - o No NDT company reported that their clients <u>never</u> inform other workers about the radiography to be performed.
    - o Just over half the companies (54%) stated that their clients <u>always</u> inform other workers about the purpose and method of the warning system, the meaning of alarm signals, and the risks of ionizing radiation. Conversely, very few (5%) companies reported that the clients never inform other workers on these matters.

Regulatory bodies:

– Only about 40% of regulatory bodies (22 out of 58) required advance notification about individual on-site industrial radiography jobs. Of those:
    - o From the 17 regulatory bodies providing data on the number of hours of advance notification, the average advance notification required was 48 hours, while the median value was 24 hours.
– Almost all regulatory bodies (56 out of 58) required the use of a warning system to prevent entry to the radiography site. Of these, 80% of regulatory bodies (47 out of 56) stated that they had an official standard procedure for such a warning system.

  - Such standard procedures typically required barriers (46 out of 46); warning signs (47 out of 47); and, flashing lights (31 out of 43).
- 43 regulatory bodies provided data on the maximum dose rate allowed at the barrier. The average was 30 µSv/hour, and the median value was 10 µSv/hour.
- Only about 40% of regulatory bodies (24 out of 58) require the client (who is receiving the on-site radiography services) to inform the NDT company about conditions at the site that might affect safety of other workers on site. Of these:
  - 70% of regulatory bodies (17 out of 23) require the client to provide the NDT company with site plans; and
  - All regulatory bodies (22 out of 22) require the client to provide the NDT company with information about other worker activities, occurring at the same time and in the vicinity of where the radiography will occur.
- Almost half of the regulatory bodies (28 out of 57) require that there is a qualified radiation protection officer or radiation protection expert on the work site during on-site radiography.

3.5.3. Safety of sources and exposure devices

NDT companies:

- 78 NDT companies provided data on the interval between preventative maintenance for exposure devices in gamma radiography – the mean and median interval between maintenance was 8 and 6 months, respectively. Two NDT companies reported that preventative maintenance was not performed.
- The auxiliary equipment reported to be included in the preventative maintenance was:
  - Control cable (100%, 81 out of 81);
  - Guide tube (100%, 81 out of 81);
  - Crank (95%, 77 out of 81);
  - Collimator (69%, 56 out of 81).
- Preventative maintenance was performed by various combinations of the NDT company itself, the device manufacturer and a third party service provider. The NDT company was involved in 72% of the responses (60 out of 83), 41% of responses for the device manufacturer, and 49% for a third party service provider.
- 67 NDT companies provided data on the interval between preventative maintenance for X-ray equipment used in industrial radiography – the mean and median interval between maintenance was 8 and 6 months, respectively. One NDT company reported that it did not perform preventative maintenance.
- The auxiliary equipment reported to be included in the preventative maintenance was:
  - Cables (88%, 65 out of 74);
  - Control panel (97%, 72 out of 74);
  - Diaphragm or collimator (72%, 53 out of 74);
  - X-ray output (78%, 57 out of 73);
  - Leakage radiation (78%, 57 out of 73).
- The preventative maintenance was performed by various combinations of the NDT company itself, the device manufacturer and a third party service provider. The NDT company was involved in 67% of the responses (50 out of 75), 32% of responses for the device manufacturer, and 55% for the third party service provider.

Regulatory bodies:

- 80% of regulatory bodies (43 out of 55) stated that they require any source used for industrial radiography purposes to meet specified standards. 31 regulatory bodies provided details on what these standards were:
    - 60% (19 out of 31) named specific ISO standards, including ISO2919:1999 RP - Sealed radioactive sources - general requirements; ISO9978:1992 RP - Sealed radioactive sources - leakage test methods; or ISO3999:2004 - Radiation protection - Apparatus for industrial gamma radiography - Specifications for performance, design and tests.
    - 26% (8 out of 31) invoked unspecified national regulations, standards or norms.
    - 19% (6 out of 31) invoked unspecified international standards.
- 80% of regulatory bodies (43 out of 55) stated that they require any exposure device used for industrial radiography purposes to meet specified standards. 33 regulatory bodies provided details on what these standards were:
    - 48% (16 out of 33) named specific ISO standards, including ISO2919:1999 RP - Sealed radioactive sources - general requirements; ISO9978:1992 RP - Sealed radioactive sources - leakage test methods; or ISO3999:2004 - Radiation protection - Apparatus for industrial gamma radiography - Specifications for performance, design and tests.
    - 30% (10 out 33) invoked unspecified national regulations, standards or norms.
    - 24% (8 out 33) invoked unspecified international standards.
- 80% of regulatory bodies (45 out of 55) require that the source and the exposure device are subject to periodic inspections to verify compliance with required standards. 35 regulatory bodies provided data on how often such inspections must occur – the average and median interval between inspections was 12 months. Of those regulatory bodies requiring inspections:
    - 90% (39 out of 43) stated that accessories are included;
    - 90% (37 out of 40) permit the manufacturer or manufacturer's agent to perform such services;
    - 70% (24 out of 36) permit the NDT company to perform such services;
    - Over 70% (25 out of 34) permit an approved third party to perform such services.
- 65% of regulatory bodies (36 out of 55) stated that they require any X-Ray generator used for industrial radiography purposes to meet specified standards. 27 regulatory bodies provided details on what these standards were:
    - 50% (13 out of 27) invoked national regulations, standards or norms;
    - 60% (16 out 27) invoked international standards.
- 70% of regulatory bodies (41 out of 56) require that the X-Ray equipment is subject to periodic inspections to verify compliance with required standards. 32 regulatory bodies provided data on how often such inspections must occur – the median interval between inspections was 12 months. Of those regulatory bodies requiring inspections:
    - 90% (33 out of 36) stated that accessories are included;
    - 90% (32 out of 35) permit the manufacturer or manufacturer's agent to perform such services;
    - 75% (23 out of 30) permit the NDT company to perform such services;
    - 80% (25 out of 31) permit an approved third party to perform such services.
- Almost all regulatory bodies (55 out of 56) specify requirements for on-site storage of sources.

- Almost all regulatory bodies (53 out of 57) require the licensee to conduct periodic documented checks of sources to confirm that they are in their assigned locations and are secure.

3.5.4. Compliance inspections

NDT companies:

- 66% of NDT companies (63 out of 95) reported that their Radiation Protection Programme (RPP) was approved by the company's managing director or chief executive officer; 62% (59 out of 95) reported approval by the company's RPO; and 61% (57 out of 93) reported approval by the regulatory body. 31% reported that all three parties approved their RPP, while no NDT company reported that their RPP was approved by none of the parties.
- Almost all NDT companies (96%, 89 out of 93) reported that they performed their own compliance inspections of their radiographers. Of these:
    - 61% reported that they performed planned (announced) compliance inspections;
    - 77% reported that they performed unplanned (unannounced) compliance inspections;
    - 42% reported that they performed both sorts of inspections;
    - Most of the compliance inspections (89%, 76 out of 85) involved the RPO. Some management team presence was reported for 42% of NDT companies;
    - From the data of 78 responses, the mean and median number of times a radiographer would be inspected by the company in a year were 4 and 2, respectively;
    - The following summarizes the percentage of company inspections that addressed:
        - Proper wearing of passive individual dosimeters – 95%;
        - Proper wearing and use of active individual dosimeters – 93%;
        - Proper use of survey meters – 95%;
        - Proper use of collimators – 90%;
        - Proper warning system at the work site – 93%;
        - Dose rate at the boundary of the work site within the limits set – 92%;
        - Proper use of alarm systems – 86%;
        - Proper training and qualifications of radiographers – 91%;
        - Operator knowledge of procedures – 88%;
        - Pre-operation specific equipment checks – 82%;
        - Equipment condition – 85%;
        - Emergency preparedness – 74%.
    - The five most common shortcomings were reported as:
        - No proper use of collimators;
        - Dose rate at the boundary of the work site not within the limits set;
        - No proper use of survey meters;
        - No pre-operation specific equipment checks being performed;
        - Poor operator knowledge of procedures.
- 66% of NDT companies (60 out of 91) reported that the regulatory body performed planned (announced) compliance inspections of the company's radiographers on the work site.
    - From the 56 responses with data, the reported mean and median number of times a year that a company radiographer would undergo a planned regulatory body inspection were 2 and 1, respectively.

- 64% of NDT companies (58 out of 91) reported that the regulatory body performed unplanned (unannounced) compliance inspections of the company's radiographers on the work site.
    - From the 51 responses with data, the reported mean and median number of times a year that a company radiographer would undergo an unplanned regulatory body inspection were 2 and 1, respectively.
- 87% of NDT companies (81 out of 93) reported that the regulatory body performed some form of compliance inspections of the company's radiographers on the work site.
    - From the 74 responses with data, the calculated mean number of times that a company radiographer would undergo a regulatory body inspection was nearly 3 times a year.
- 40% of NDT companies (37 out of 93) reported that the regulatory body performed both planned (announced) and unplanned (unannounced) compliance inspections of the company's radiographers on the work site.
    - From the 33 responses with data, the calculated mean number of times that a company radiographer would undergo a regulatory body inspection was approximately 4 times a year, with 2 being planned and 2 being unplanned.
- 13% of NDT companies (12 out of 93) reported that the regulatory body performed neither planned or unplanned (unannounced) compliance inspections of the company's radiographers on the work site.

Regulatory bodies:

- Over 90% of regulatory bodies (54 out of 58) stated that they perform inspections of NDT companies that provide on-site radiography services. Of these, 85% (46 out of 54) perform inspection where on-site radiography is actually taking place. Further, of the inspections:
    - 26% (14 out of 53) are announced only;
    - 2% (1 out of 53) are unannounced only; and
    - 72% (38 out of 53) are either announced or unannounced.
- From the data of 46 regulatory bodies, the average and the median number of regulatory inspections were both 1 per year. Most regulatory inspections addressed similar elements, including:
    - Wearing of passive dosimeters – 98% (51 out of 52);
    - Wearing of active dosimeters – 90% (46 out of 51);
    - Use of survey meters – 96% (50 out of 52);
    - Use of collimators – 88% (44 out of 50);
    - Use of warning systems to prevent entry to the work site – 98% (51 out of 52);
    - Dose rate at the boundary of the warning system – 90% (47 out of 52);
    - Use of alarm systems – 96% (49 out of 51);
    - Training and qualifications of radiographers – 100% (52 out of 52);
    - Operator knowledge of procedures – 96% (47 out of 49);
    - Pre-operation equipment checks – 86% (42 out of 49);
    - Equipment condition – 98% (49 out of 50);
    - Emergency preparedness – 96% (47 out of 49).
- Based on the responses from 54 regulatory bodies, the 5 most common shortcomings were:
    - 1st – No proper use of survey meters;
    - 2nd – No proper warning system to prevent entry to the work site;
    - 3rd – Poor emergency preparedness;
    - 4th – No proper use of alarm systems;

  - 5th – Dose rate at the boundary for the work site not within limits set.

3.5.5. Emergency preparedness and response

Individual industrial radiographers:

- Over 90% of radiographers (385 out of 412) stated that the NDT company they worked for had an emergency plan for site radiography. Of these, almost 90% (338 out of 379) said that they had received training for the roles and responsibilities of radiographers in that emergency plan.

NDT companies:

- Almost all NDT companies (95%, 90 out of 95) stated that they had an emergency plan and procedures for responding to incidents during the performance of site radiography. Of the four “no” responses, all were X-ray only NDT companies.
- The emergency plan is communicated and discussed with:
  - Company radiographers – over 90% of NDT companies (82 out of 88);
  - Company clients – less than half of NDT companies (42 out of 85);
  - The regulatory body – 82% of NDT companies (69 out of 84);
  - Other emergency response authorities – 44% of NDT companies (36 out of 82).
- All responding NDT companies communicated and discussed their emergency plan with at least one of the above parties. 26 NDT companies stated that they communicated and discussed their emergency plan with all of the above parties.
- 82% of NDT companies (78 out of 95) stated that they provided specific training to their radiographers on emergency preparedness and response. This specific training included:
  - Explanation of emergency procedures – effectively all, with 77 out of 78, and one “no reply”;
  - Practical exercises on containment of the situation – 90%, 69 out of 77;
  - Practical exercises on source recovery – 73%, 53 out of 73.
- The 16 “no” answers with respect to specific training on emergency preparedness and response were dominated by 13 from Europe. It is likely that these responses reflect the practice and requirements to use specialist persons in emergency roles, and hence training radiographers for this role is not considered appropriate.
- 91% of NDT companies (85 out of 93) stated that they have emergency equipment for site radiography. Emergency equipment included:
  - Long tongs – 89% of NDT companies (74 out of 83);
  - Shielding material – 98% of NDT companies (80 out of 82);
  - Emergency or rescue container – 79% of NDT companies (64 out of 81);
  - Other equipment included protective clothing (6 responses), cutting equipment (6), additional survey meters (long) and dosimeters (4), fire extinguishers (2), first aid kit (1), and toolbox (1).
- 92% of NDT companies (77 out of 84) stated that their radiographers have access to emergency equipment.
- In reply to the questions on responsibilities at the various stages of an emergency, the following can be summarized:
  - Responsibility for containment of the situation:
    - The radiographer and the RPO for most NDT companies (78%, 68 out of 89). There were no responses where the radiographer or the RPO were not involved.

- o Responsibility for planning and rehearsing the recovery:
  - ▪ Primarily the RPO (87%, 75 out of 86), with a supporting role of the radiographer (44%, 38 out of 86). There were 4 responses where the radiographer or the RPO were not involved.
- o Responsibility for recovery of the situation:
  - ▪ Primarily the RPO (77%, 67 out of 87), with a supporting role of the radiographer (46%, 40 out of 87). There were 3 responses where the radiographer or the RPO were not involved.
- o Responsibility for investigating and reporting:
  - ▪ Primarily the RPO (89%, 77 out of 87), with a supporting role of the radiographer (34%, 30 out of 87). There were 3 responses where the radiographer or the RPO were not involved.

- – Just over half of NDT companies (56%, 49 out of 87) stated that they hold emergency exercises to test the critical components of the company's emergency plan.
  - o From those that responded that they do hold exercises, the mean number of exercises per year was 2 and the median number was 1.
- – Nearly two-thirds of NDT companies (63%, 54 out of 86) stated that they undertake periodic formal reviews of the company's emergency plan.
  - o From those that responded that they do undertake reviews, the mean and median number of reviews per year was 1.

Regulatory bodies:

- – Almost all regulatory bodies (57 out of 58) stated that they require NDT companies to have an emergency plan. Three-quarters of the regulatory bodies (43 out of 57) require the emergency plan to specify requirements for training and exercises. 80% of regulatory bodies (43 out of 55) stated that they approve an NDT company's emergency plan.
- – Three-quarters of the regulatory bodies (43 out of 57) require licensees to have emergency equipment.
- – 60% of regulatory bodies (35 out of 57) stated that they have resources to assist licensees in recovering from emergencies.
- – 90% of regulatory bodies (52 out of 57) stated that they check the emergency plan and equipment during periodic inspections or at licence renewal.

3.6. INDIVIDUAL MONITORING

Individual industrial radiographers:

- – Over 90% of radiographers (387 out of 423) stated that they knew what occupational doses they received. The mean number of times per year that the radiographer was informed about their dose was 11 times, and the median number was 12 times. This is consistent with 1 month or 4 weeks being the most commonly reported monitoring periods (73%).
- – Over 200 radiographers gave a value for their annual occupational effective dose in 2009:
  - o The average was dose for 2009 was 3.4 mSv, with a reported maximum annual effective dose of 30 mSv.
  - o While the majority of radiographers (76%) stated that they received an annual effective dose of less than 5 mSv in 2009, nearly one-quarter received a dose

between 5 and 20 mSv, and a small percentage (2%) received a dose greater than 20 mSv.
    - Regional details are given in Appendix I, Tables I.15a & I.15b and Figure I.1.
- Almost 200 radiographers gave a value for their maximum dose for a monitoring period in 2009. Results were normalized to a 1 month monitoring period:
    - Nearly 70% of radiographers (122 out of 181) had a maximum monthly dose in 2009 of less than 1 mSv. The mean maximum monthly dose was 1.4 mSv and the median 0.5 mSv.
    - One radiographer had a maximum monthly dose in 2009 exceeding 20 mSv.
    - 4% of radiographers (7 out of 181) had a maximum monthly dose in 2009 exceeding 5 mSv.
    - On average, approximately one-third of the annual dose is received in the month with the highest dose.
    - More details are given in Appendix I, Tables I.16a & I.16b and Figures I.1a & I.2.
- Based on data from 141 radiographers who provided both annual doses and workloads, the estimate (at the 95% level) of mean occupational dose per exposure was 4.8 ± 2.3 µSv. If data for radiographers with very low workloads are excluded (less than 100 exposures per year), 129 data points remained, giving an estimate of mean occupational dose per exposure of 2.9 ± 1.2 µSv.
- There was no statistically significant difference between the mean occupational dose per exposure for those radiographers who worked with gamma sources only and those who worked with X-Ray sources only. (See also Appendix I, Table I.18a and Figures I.4 & I.5).
- For those radiographers who worked with Ir-192 sources in 2009, there was no strong correlation of annual occupational dose with source activity, and no strong correlation of occupational dose per exposure with source activity. However, in both cases, the correlation was stronger for radiographers who worked with Ir-192 sources only compared with those radiographers who worked with other sources as well as Ir-192. (See also Appendix I, Figures I.6 to I.9).
- There was no statistically significant difference between the mean occupational dose per exposure for those radiographers who always used collimators when working with gamma sources compared with those who only sometimes used collimators. (See also Appendix I, Table I.19a and Figures I.10 & I.11).
- There was no statistically significant difference between the mean occupational dose per exposure for those radiographers who always used diaphragms/collimators when working with X-Ray sources compared with those who never used diaphragms/collimators. (See also Appendix I, Table I.19b and Figures I.12 & I.13).
- There was no statistically significant difference between the mean occupational dose per exposure for radiographers with level 3 NDT training compared with level 2 or level 1 radiographers. (See also Appendix I, Table I.20a & I.20b and Figures I.14 & I.15).
- There was no correlation between the annual occupational effective dose in 2009 and the total number of events (accidents, near misses and deviations), or each separately. Similarly, there was no correlation for the highest monthly occupational dose, or for the occupational dose per exposure. (See also Appendix I, Tables I.21a, b, & c and Figures I.16 & I.17).
- There was no statistically significant difference between the estimates of mean annual effective dose for the radiographers who had had events in the last 5 years compared with

those radiographers who had not had events. Similarly for the estimates of mean occupational dose per exposure. (See also Appendix I, Figures I.18 & I.19).

NDT companies:

- 76 NDT companies provided banded annual dose data for a total of 3375 industrial radiographers for the year 2009. Over half (58%) had an estimated annual effective dose less than the 1 mSv. A small percentage (0.3%) had an estimated annual effective dose greater than or equal to the dose limit of 20 mSv.

Regulatory bodies:

- 60% of regulatory bodies (34 out of 55) stated that they have direct access to a national or state database of individual doses for industrial radiographers and other workers involved in NDT.
- 33 regulatory bodies were able to supply annual dose data for industrial radiographers for the year 2009:
  - The average annual effective dose for nearly 18,000 monitored industrial radiographers, from 33 countries, was 2.9 mSv, with a reported maximum annual effective dose of 158 mSv.
  - While the vast majority of industrial radiographers (86%) received an annual effective dose of less than 5 mSv in 2009, nearly 350 persons (2%) received a dose greater than 20 mSv, and nearly 50 persons (0.3%) received a dose greater than 50 mSv.
  - The average annual effective dose for nearly 5,000 monitored "other NDT workers", from 10 countries, was 0.6 mSv, with a reported maximum annual effective dose of 91 mSv.
  - 99% of "other NDT workers" received an annual effective dose of less than 5 mSv in 2009.
  - From the distribution of country-average annual effective doses:
    - The mean country-average effective dose for industrial radiographers was 2.2±0.8 mSv for 2009; and
    - The mean country-average effective dose for "other NDT workers" was 1.2±0.8 mSv for 2009.
- 21 regulatory bodies were able to supply data on the maximum monthly dose for industrial radiographers for the year 2009:
  - 90% of industrial radiographers (8201 out of 9144) had a maximum monthly dose in 2009 of less than 1 mSv.
  - 3 radiographers had a maximum monthly dose in 2009 exceeding 50 mSv.
  - 2% of radiographers (187 out of 9144) had a maximum monthly dose in 2009 exceeding 5 mSv.
  - 98% of "other NDT workers" (3572 out of 3642) had a maximum monthly dose in 2009 of less than 1 mSv.
- About one-half of regulatory bodies (17 out of 30) stated that they perform trend analysis of the occupational doses in industrial radiography. All of these regulatory bodies stated that they use the results of the analyses to improve radiation protection in industrial radiography.

4. DISCUSSION

As noted above in sub-section 3.1 on caveats, caution must be exercised in drawing conclusions from the survey results. Nevertheless, some comments and discussion follow on particular topics. Further, having the three questionnaires with responses from the three different sources – radiographers, NDT companies and regulatory bodies – provides different perspectives on the various topics, and allows comparisons to be made. Additional comments appear in the Appendices as notes to some of the tables and figures.

There are other aspects that affect radiation safety in industrial radiography, which the results of the survey are likely to have glossed over. The first is that while an NDT company may have a manual with a comprehensive set of safe operating procedures, this does not necessarily translate into the use of those procedures in actual practice in the field. Some hint of the extent of this problem is evident in the comparison of results for company responses with those for the radiographers – see section 4.3.1 below, for example.

A second aspect is that clients can bring undue pressure upon the NDT company, and hence the industrial radiographers, to complete a given task in a constrained period of time or a set of adverse conditions. A third related aspect is that an NDT company may be operating on a very narrow profit margin in order to secure a given contract. In both these cases, corners are likely to be cut, and radiation protection and safety likely to be compromised. The effect of such issues is unlikely to have fully emerged in the results of the survey.

4.1. RADIATION PROTECTION TRAINING AND QUALIFICATIONS OF INDUSTRIAL RADIOGRAPHERS

The need for radiation protection training in industrial radiography appears to be well accepted and established. On the one hand, the regulatory bodies almost universally stated that they require radiation protection training for radiographers, and on the other hand almost all the NDT companies provided or facilitated initial radiation protection training. The result was that the radiographer responses indicated a high prevalence of radiation protection training, with only 8 responding radiographers (2%) stating that they had not had radiation protection training. It should have been zero radiographers having had no radiation protection training, but nonetheless the result is very much towards the desired situation.

Most regulatory bodies (90%) required the radiation protection training to include both theory and practical. Data from the NDT companies showed that almost all (96%) gave initial theoretical training in radiation protection, with a mean of nearly 40 hours, but a lower number (82%) gave initial practical training in radiation protection, with a mean of 30 hours. This appears to be in addition to any radiation protection training received as part of the NDT training, as indicated by the radiographer responses where the greater majority (85%) stated that they had received radiation protection training separate to the NDT training.

Refresher training was less well established, with only 70% of regulatory bodies stating that they required refresher training in radiation protection for persons performing on-site radiography. Almost 20% of NDT companies reported that they did not provide or facilitate refresher theoretical training in radiation protection, and a larger percentage (40%) reported that they did not provide or facilitate refresher practical training in radiation protection. Clearly, there is scope for improvement.

The question of specific training for emergency situations is an interesting one. The majority of radiographers (89%) reported that procedures for emergencies were included in their radiation protection training. However, only two-thirds said that the training included practical exercises for creating a safe situation until the source is able to be recovered, and just over half said that the training included practical exercises for source recovery. Three-quarters of the radiographers stated that they were not allowed to perform a source recovery on their own without first contacting a specialized source recovery person. Regardless of the authority of radiographers to actually perform source recovery, given the likelihood of emergencies and the associated very real health hazards it should seem essential that all radiographers are well trained with respect to procedures for emergencies.

The NDT companies were asked about training for emergencies in two parts of their questionnaire. In the section on radiation protection education and training (in question1c) almost all (90 out of 92) stated that their training included emergency procedures. However, in the section on emergency preparedness and response (question 24), the lower number of 78 stated that they provided specific training to their radiographers on emergency preparedness and response. Of twelve who had said "yes" to question 1c(i), eleven then said "no" to question 24, and one said they did not know. Perhaps there were perceived differences in the two questions, and it was noted that the NDT companies that said "no" to question 24 were predominantly from Europe and likely reflected the practice and requirements to use specialist persons in emergency roles. Perhaps more reassuringly, only two NDT companies said "no" to both questions, although again this should arguably have been zero.

The influence of different country and regional approaches to dealing with emergencies was further evident in the results for the practical training on containment of the situation and creating a safe situation and on source recovery. In both areas of training, the percentages for Europe, North America and Africa were lower than for Asia-Pacific and Latin America.

From the regulatory perspective, the regulatory body responses showed that about 70% require the radiation protection training to include practical exercises for creating a safe situation in an emergency until the source is able to be recovered, with a lower percentage (about 60%) requiring practical exercises for source recovery.

It would seem essential that all radiographers who perform on-site radiography be trained in emergency procedures and understand their role and what specific steps they are required to be involved in to create a safe situation, regardless of who will ultimately perform the source recovery.

The concerns expressed here are perhaps echoed in the radiographer responses to the question on "do you feel sufficiently well qualified and trained to be able to work safely and reliably?", to which less than 2% of radiographers replied "no", but about 10% replied that they did not feel well prepared for an emergency situation.

It was perhaps surprising that, while almost all regulatory bodies (57 out of 59) stated that any person wishing to act as an RPO for a company that performs on-site radiography must have had radiation protection training to an acceptable level, only 70% (39 out of 57) thought that the acceptable level was higher than that for a radiographer. It would seem essential that in an industry with a track record of accidents and incidents that the RPO really needs to have specialist expertise in radiation protection. This would, therefore, seem to be an area for improvement.

4.2. INCIDENTS (DEVIATIONS, NEAR MISSES AND ACCIDENTS)

Accidents, near misses and deviations are widely recognized as being a characteristic of industrial radiography [1], and the results of this survey provide such confirmation – they do occur. It is likely that the reported values in the survey are an underestimate, especially with regard to near misses and deviations.

Rates of occurrence of accidents, near-misses and deviations were reported by both the radiographers and the NDT companies. Tables 1 and 2 compare the derived rates of incidence from the two sources for each of accidents, near misses and deviations. The estimates of rates of incidence for radiographers were obtained directly from the radiographer responses and derived from the NDT company responses by scaling the company incidence by the number of radiographers in that company. Similarly, the estimates of rates of incidence for NDT companies were obtained directly from the NDT company responses and derived from the radiographer responses by scaling the radiographer incidence by the number of radiographers in that company.

Table 1. Estimates of the incidence rates of accidents, near misses and deviations per radiographer per 5 years, estimated from the radiographer responses and the NDT company responses.

	Radiographer data	**NDT company data**
Incidence of:	Per radiographer per 5 years	Per radiographer per 5 years
Accidents	0.04	0.03
Near misses	0.1	0.05
Deviations	0.6	0.05

Table 2. Estimates of the incidence rates of accidents, near misses and deviations per NDT company per 5 years, estimated from the radiographer responses and the NDT company responses.

	Radiographer data	**NDT company data**
Incidence of:	Per NDT company per 5 years	Per NDT company per 5 years
Accidents	4.0	1.1
Near misses	6.2	1.8
Deviations	29.3	1.8

While there are uncertainties associated with the data, in each case the estimate from the NDT company data was less than the corresponding estimate from the radiographer data, especially for near misses and deviations. This would suggest that there is a knowledge gap between what occurs in the field versus what is known or acknowledged back at headquarters. There may be reluctance for a radiographer to report an incident for fear of repercussions, or there may be reluctance for NDT companies to acknowledge that incidents are happening in their company. A safety culture needs to be promoted in all NDT companies, whereby reporting of incidents is not only encouraged but is also seen by all as adding value to radiation safety by providing the opportunity to learn and to improve.

Sharing information about radiation incidents is a well-recognized means for minimizing the likelihood of similar incidents elsewhere, but the level of dissemination appears to be less than desirable. While almost all NDT companies had one or more means for doing this within their companies, there was a sizeable proportion (nearly 40%) that did not appear to share information on incidents with other organizations.

Almost all regulatory bodies reported that they had established criteria for when it was a requirement to report an incident to the regulatory body. For the more serious accidents, reporting to the regulatory body by the NDT company appeared to be well implemented – 100% for accidents with individual exposures higher than the annual dose limits, and 70% for accidents with elevated individual exposures, but lower than the dose limits. Statistics from the regulatory body perspective gave an accident incidence of nearly 5 accidents per jurisdiction per 5 years. As with the radiographers above, there may be reticence for an NDT company to report an incident for fear of regulatory actions. Again, the more incidents that are reported, the greater the scope for learning and for dissemination of information to minimize the likelihood of recurrences.

Only two-thirds of regulatory bodies stated that they maintain a radiation incident database for their jurisdiction, resulting in slightly less than half of the regulatory bodies analysing data regularly to determine if there are common factors in the incidents. Again, only about one-half of the regulatory bodies reported having an established system for sharing lessons learned from reported incidents, reiterating the comment above on poor dissemination.

Means for minimizing the likelihood of incidents remains a priority in industrial radiography, and the survey results indicate there is room for improvement in reporting incidents from the field to the company, and from the company to the regulatory body. For the latter, more regulatory bodies should consider establishing an incident database which would then facilitate the dissemination of lessons learned.

4.3. SYSTEMS AND PROCEDURES TO ENSURE PROTECTION AND SAFETY IN INDUSTRIAL RADIOGRAPHY

4.3.1. Safety of the radiographer

Safety of the radiographer is ensured through having good work and radiation protection practices and confirming this with appropriate dosimetry and monitoring.

Most, but not all, radiographers reported checking for the presence of the source in the exposure device before taking the device from the store, and checking after completing the NDT exposure. Knowledge about where the source is at all times is crucial in preventing accidents, and cannot be overstressed. All radiographers should be routinely performing these checks each and every time.

Collimators are used to reduce the radiation beam in some directions. They should be used whenever possible, to reduce radiation levels and subsequent occupational doses. A very small percentage of radiographers (< 1%) said they never used collimators when performing gamma radiography, but about 10% said they never used diaphragms/collimators for X-ray radiography. From the company perspective, over 90% said they required collimators to be used for gamma radiography and this can be compared with the radiographers from the same companies of whom only 80% said that they always used collimators. For X-ray radiography, almost 80% of NDT companies stated that they required the use of diaphragms/collimators, but the radiographer responses for 8 out of 45 of these companies suggested that some radiographers were not using diaphragms/collimators despite the company requirement. Clearly, there is room for improved practice.

The survey meter plays an important radiation safety role in industrial radiography. Almost all regulatory bodies (95%) stated that they require an industrial radiographer to always have a functioning and calibrated survey meter with them. Almost the same percentage of NDT companies (91%) stated that they provide survey meters. Unfortunately, the radiographer questionnaire did not ask about the presence and use of survey meters. Perhaps an estimate of use is given by the percentage of radiographers that check for the presence of the source in the exposure device after performing NDT exposures – namely, 95%. While all these percentages are high, each should really be 100%.

The RPO has a role to play in promoting good practice in the field. Most (90%), but not all, regulatory bodies stated that they require an NDT company to employ an RPO or RPE, and almost all NDT companies (97%) stated that they have an RPO or RPE in their organization. However presence in the field is another issue. About one-half of the regulatory bodies required an RPO to be present on the work site during on-site radiography. This aligns well with about 55% of radiographers reporting that an RPO or RPE was on site during on-site radiography. This implies that in almost half of the companies and for almost half the radiographers, on-site radiography is being performed without the benefit of radiation protection knowledge of the RPO. It was also less than satisfactory that 20% of radiographers reported that they did not have regular discussions with their RPO on radiation protection issues or their occupational doses.

All regulatory bodies stated that they required radiographers to use passive dosimeters. While about 80% also required the use of active dosimeters, this means that there were about 20% of regulatory bodies who had no expectation that radiographers need to have active dosimeters with alarm functions. Most active dosimeters had audible alarms, but fewer had visual or vibrating alarms. Using active dosimeters that utilize three senses rather than just one would seem to provide additional radiation safety, especially in the often hazardous environment in which the radiography is taking place. It was reassuring that all NDT companies stated that they provided their radiographers with at least one form of dosimeter. However, only 90% of radiographers stated that they knew what occupational doses they received. The implication is that the other 10% did not use dosimeters, either because dosimeters were not provided or the radiographers chose not to use them, or perhaps that they were uninterested in their doses.

The role of investigation levels could be more widely utilized. Less than two-thirds of NDT companies reported that they had established their own investigation levels, although a higher percentage said that the regulatory body had set such a level. All NDT companies should be using investigation levels. Of those that did have investigation levels, almost half reported that they had not performed any investigations in the last 5 years. This could be indicative of good practice, or it could suggest that investigation levels are set too high.

4.3.2. Safety of the public

Radiation protection for the public is afforded through ensuring that dose rates in areas accessible to the public are at levels which cannot lead to the public dose limits being exceeded, and by ensuring that members of the public do not enter a site where radiography is taking place.

Clearly, warning systems form an important part of protecting the public. Almost all regulatory bodies required the use of a warning system to prevent entry to the radiography site. Most of the regulatory bodies (80%) stated that they have a standard procedure for such a warning system, based mainly on barriers, and warning signs and lights. The average maximum dose rate allowed at the barrier, as set by the regulatory bodies, was 30 µSv/hr with a median of 10 µSv/hr. These values can be compared with the NDT company reported values of 13 µSv/h and 7.5 µSv/h for the mean and median, respectively, both of which are less than the regulatory body values.

One group of the public that are at particular risk with site radiography are other workers at the site. It is self-evident that these workers need to be aware that radiography is taking place, and that they need to understand the meaning of signage and warning lights. Conversely, the industrial radiographers need to know about particular aspects of the site that they are working at, including interfering activities. The results of the survey suggest that communication between the NDT company and the client is less than desirable. For example, the regulatory impetus is lacking – less than half of the regulatory bodies require the client (who is receiving the on-site radiography services) to inform the NDT company about conditions on the site that might affect the safety of other workers on site. This is then reflected in practice where the majority (70%), but not all, of NDT companies reported that their clients always provide information about other interfering activities on site.

A sizable proportion (60%) of NDT companies said that they had analysed reasons why unauthorized persons trespassed past the warning system. Wilful violation was the main cause, followed by ignorance about the meaning or purpose of the warning system. Both of these could be addressed through better communication between the NDT company and the client.

4.3.3. Safety of sources and exposure devices

Regulatory performance requirements set the basis for safety of sources and exposure devices. Most regulatory bodies (80%) stated that they required sources and exposure devices used for industrial radiography to meet specified standards, and 75% required X-ray generators used for industrial radiography to meet specified standards.

Further, 80% of regulatory bodies required that the source and the exposure device be subject to periodic inspections/tests and maintenance to verify compliance with the required standards. For X-ray generators, periodic inspections/tests and maintenance were required by 70% of regulatory bodies. This can be compared with the NDT company responses, where only 2 companies (2%) stated that preventative maintenance was not performed for exposure devices for gamma radiography, and only 1 company (1%) stated that preventative maintenance was not performed for X-ray equipment.

The average interval specified by the regulatory bodies was 12 months for both gamma radiography devices and X-ray equipment. The NDT company data gave an average interval of 8 months, again for both gamma and X-ray devices, suggesting that the practice in industry is better than current regulatory requirements.

4.3.4. Compliance inspections

Checking that actual practice is indeed as it is supposed to be is an important part of radiation protection. High percentages of both the NDT companies and the regulatory bodies were performing compliance inspections of the radiographers at work. Both announced and unannounced inspections were being used. The results suggest that a radiographer could expect to be inspected at least twice a year by their NDT company and about once or twice a year by the regulatory body.

Both the NDT companies and regulatory bodies were asked in their respective questionnaires to rank the 5 most common shortcomings in their inspections. Table 3 compares these shortcomings. Two shortcomings were common – poor use of survey meters and dose rates at the boundary of the work site not being within limits. Two further related shortcomings of the regulatory body inspections (no proper warning systems to prevent entry to the work site and no proper use of alarm systems) were rated 6th and 7th respectively in the NDT company shortcomings. However, two of the shortcomings for NDT company inspections (poor use of collimators and no pre-operation specific equipment checks being performed) rated near the bottom of the regulatory body inspections' shortcomings.

It is possible that the results of the shortcomings reflect the different focus of the two forms of inspection – the NDT company inspections perhaps focussing more on whether the radiographer is following company procedures and protocols, while the regulatory body inspections may have a focus on public protection. Nonetheless, all the shortcomings have implications for radiation safety, and that shortcomings are found reinforces the continuing need for regular inspections.

Table 3. The five most common shortcomings for each of NDT company and regulatory body inspections.

Five most common shortcomings	
NDT company inspections	**Regulatory body inspections**
No proper use of collimators	No proper use of survey meters
Dose rate at the boundary of the work site not within limits set	No proper warning system to prevent entry to the work site
No proper use of survey meters	Poor emergency preparedness
No pre-operation specific equipment checks being performed	No proper use of alarm systems
Poor operator knowledge of procedures	Dose rate at the boundary of the work site not within limits set

4.3.5. Emergency preparedness and response

Radiation sources used for industrial radiography purposes have high radiation outputs and are potentially very hazardous. Incidents do occur and it is essential that systems are in place for emergency preparedness and response, in particular an emergency plan.

Almost all regulatory bodies (98%) stated that they require NDT companies to have an emergency plan; 95% of NDT companies stated that they had an emergency plan; and over 90% of radiographers stated that their NDT company had an emergency plan for site radiography.

The role of the radiographer in an emergency is crucial. Again, there seemed to be consistency across the questionnaires with almost 90% of radiographers reporting that they had received training for the roles and responsibilities of radiographers in the emergency plan; over 90% of NDT companies stated that their emergency plan was discussed with their radiographers and over 80% reported provided specific training on emergency preparedness and response. The last figure reflects the practice that some countries have requirements to use specialist persons in emergency roles, and hence specific training for radiographers in this role is not seen as appropriate.

Only three-quarters of regulatory bodies required NDT companies to have emergency equipment. However, 90% of NDT companies stated that they had emergency equipment for site radiography – primarily long tongs, shielding material, and an emergency or rescue container.

4.4. INDIVIDUAL MONITORING

Figure 1 (next page) shows a comparison of the occupational dose distributions for industrial radiographers in 2009 assessed from the different questionnaires. The radiographer data are for 234 radiographers, the NDT company data are for nearly 3500 radiographers, and the regulatory body data are for over 16000 radiographers. Reassuringly, there is broad agreement with the average annual effective dose from the radiographers' data and the regulatory bodies' data being 3.4 and 2.9 mSv, respectively. Some differences are, however, evident. For example, both the regulatory body data and the NDT company data show a higher proportion of radiographers receiving an annual dose less than 1 mSv – 60% and 58% respectively, while the radiographer data gave a lower proportion of 37%. Conversely, the radiographer-based data would suggest about twice as many radiographers receiving an annual dose in the range of 5–20 mSv compared with the NDT company and regulatory body data, namely 22% versus 9% and 12% respectively. The role of individual monitoring in industrial radiography is undisputed, with the need for good record keeping and regular review.

Figure 2 (next page) shows the distribution of annual effective dose for industrial radiographers versus their reported annual workloads. Clearly, there is no correlation. This emphasizes that occupational radiation protection in industrial radiography is not being effectively optimized.

Many factors can potentially affect occupational exposure in industrial radiography and there needs to be a systematic approach to the implementation of optimization of protection. The results of the survey are being used in this respect in two ways.

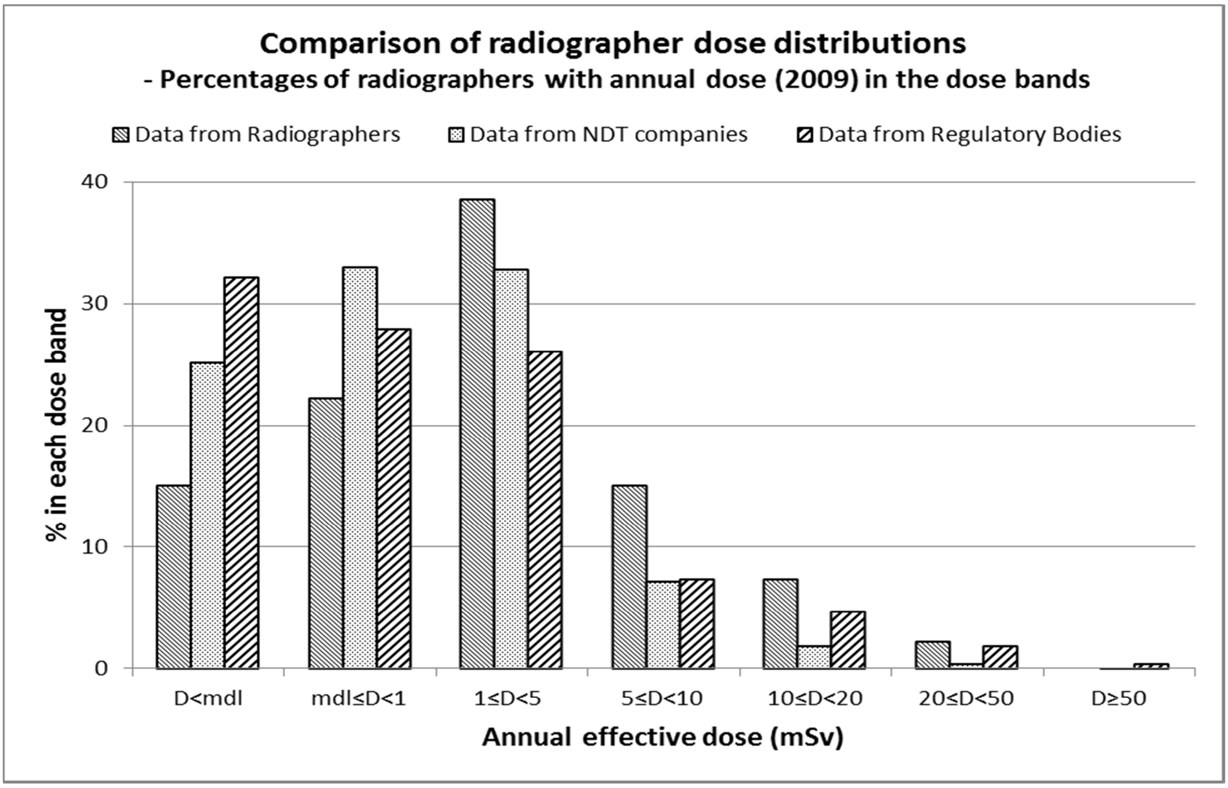

FIG. 1. Comparison of the annual dose distributions for industrial radiographers derived from the data from the radiographer questionnaire, the NDT company questionnaire and the regulatory body questionnaire. Note: 'mdl' means the minimum detection limit of the dosimetry system.

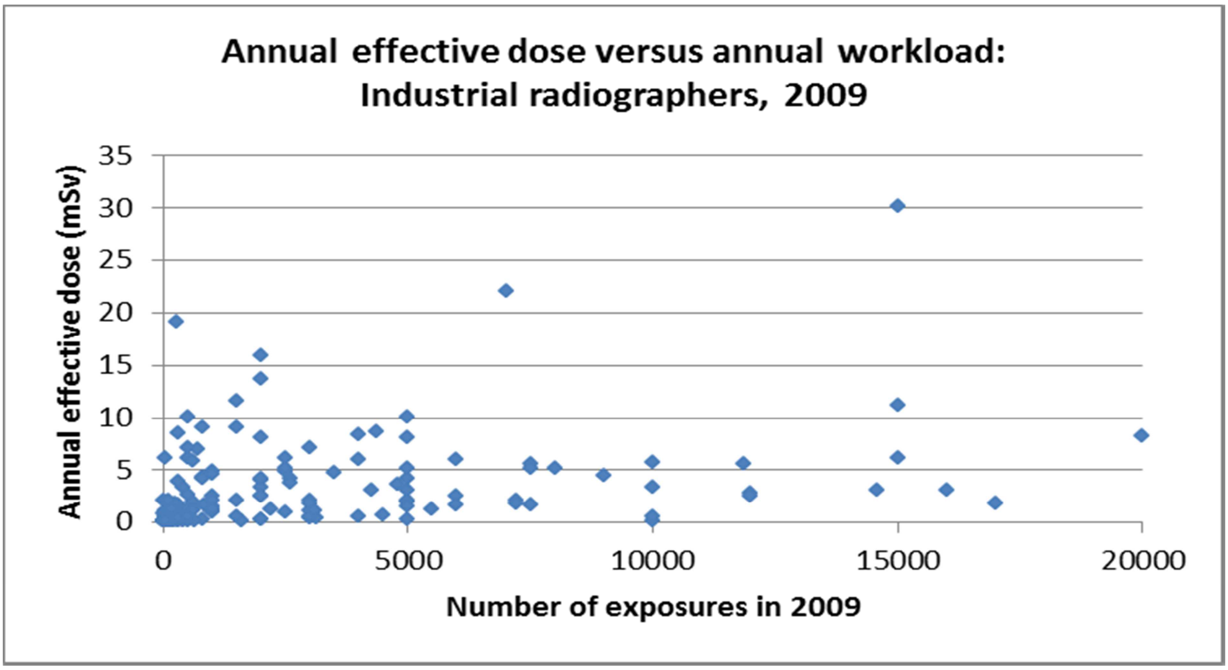

FIG. 2. The annual effective dose in 2009 for industrial radiographers versus the number of radiographic exposures for that radiographer. There was no correlation between dose and workload.

4.5. IMPLICATIONS FOR AN INTERNATIONAL DATABASE

Regulatory body data on individual radiographer occupational doses is purely for assessing compliance with the occupational dose limits. However, a database that contained information on individual industrial radiographers, including their occupational doses, radiographic workloads, level of NDT training, radiation protection training, sources used, percentage of site radiography, use of collimators, survey meters, and number of incidents, could be used as a tool by NDT companies to improve their implementation of optimization in occupational radiation protection. The establishment of such an international database is one of the long-term goals of the ISEMIR project.

The metric for assessing optimization of radiation protection would be occupational dose per radiographic exposure, and this would be able to be correlated with any of the aforementioned attributes. Global and regional analyses would provide statistics on the relationships between dose and the personnel attributes. NDT facilities would be able to benchmark their own facility and individual radiographers' performances against global or regional data. Individuals and facilities would be anonymised in the database.

Figure 3 (next page) illustrates how the ISEMIR international database would assist. The graph shows occupational dose per radiographic exposure as a function of whether collimators are always used or only sometimes used when performing radiography with gamma sources. For the sample from the questionnaire, the mean for the former was 3.3 µSv, and the latter 4.2 µSv. The difference was not statistically significant, but it illustrates the analysis that could be made with the potential power of a larger international database.

The industrial radiography section of the database would also have a module devoted to incidents – accidents, near misses and deviations from normal. This module is intended to be a tool to provide information that should lead to a reduction in the occurrence of incidents in industrial radiography. Its features would include examples of incidents for training; the ability to search for incidents related to a given factor, such as cause, equipment, conditions; provision of details on actual corrective actions implemented; and promotion of lessons learned.

Once developed, NDT facilities all around the world would be encouraged to actively participate in the database to enable it to become a viable tool for implementing optimization of occupational radiation protection in industrial radiography.

4.6. A ROAD MAP

A second output from the survey is a "road map" – a software tool that will enable NDT companies to assess their own performance in radiation protection against accepted practice. It is divided into 8 sections, namely: 1. Qualifications and training of industrial radiographers in radiation protection; 2. Learning from incidents (deviations from normal, near misses and accidents); 3. Individual monitoring; 4. Work place monitoring and warning systems; 5. Client interfaces; 6. Equipment; 7. Internal control and inspections; and 8. Emergency preparedness and response. In each of these sections there are a series of questions addressing particular aspects of each of these topics.

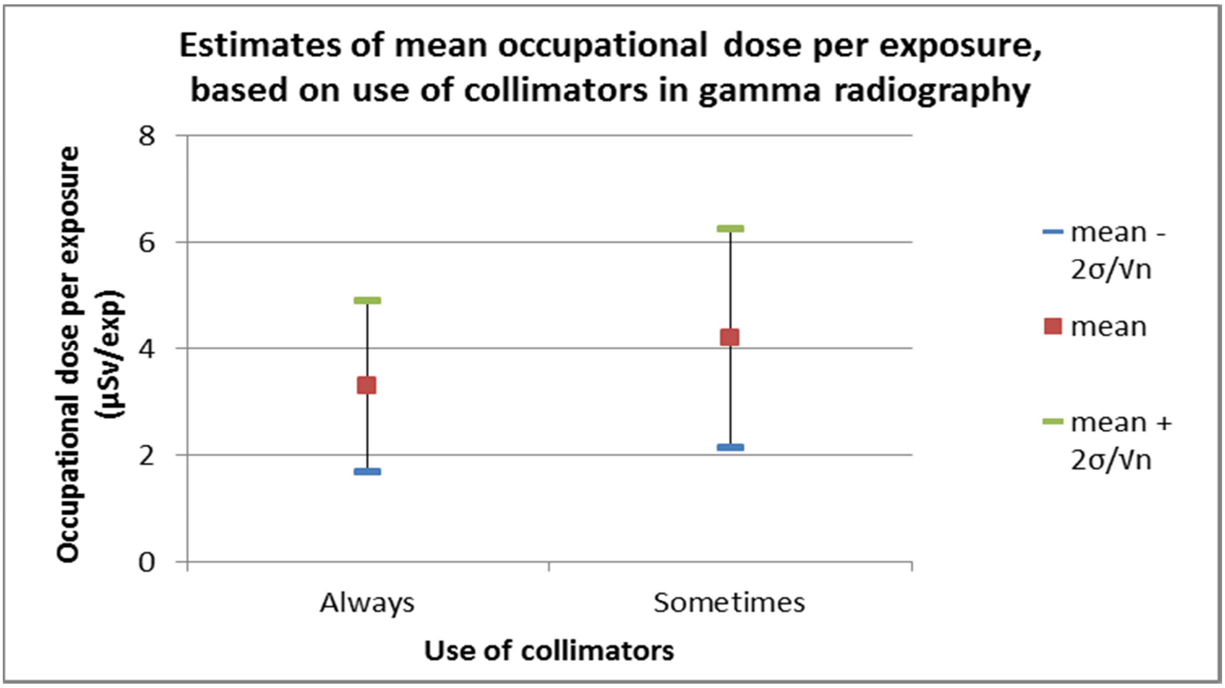

FIG. 3. Estimates of mean occupational dose per radiographic exposure when performing industrial radiography with gamma sources, as a function of whether collimators are always used or only sometimes used. The mean for the former was 3.3 µSv, and the latter 4.2 µSv. For the sample from the questionnaire, the difference was not statistically significant, but it illustrates the potential power of a larger international database.

A representative from an NDT company would answer the questions in the road map, based on current practice in their company. The response to each question is then scored by comparing it with a measure of good practice. The measure for good practice, for each question, is based either on the relevant third quartile value from the distribution of responses from the survey or on a value given in an international standard. Different weightings are applied to questions, depending on their relative importance, as established by an international group of experts. The scores for each section are summed and the results are presented to the user, including a graphical schematic that gives a quick visual overview of how the NDT company compares with current good practice. Areas that have been identified as being below par could then be addressed by the NDT company to improve occupational radiation protection in their facility. The road map tool will become available on the ISEMIR pages of the IAEA's ORPNET website at:
http://www-ns.iaea.org/tech-areas/communication-networks/norp/isemir-web.htm .

5. RECOMMENDATIONS

Based on the results of the survey, the WGIR considers the following recommendations to be appropriate:

- NDT companies should provide or facilitate initial training on radiation protection in industrial radiography, of at least one week duration and include at least two days of practical. Such radiation protection training is in addition to any that may have been received in the course of the NDT training.

- NDT companies should provide or facilitate refresher training on radiation protection in industrial radiography at least once every year, of at least one day duration and should include a practical exercise for creating a safe situation after a typical accident.
- Every NDT company should have an approved RPP, supported and regularly reviewed by top management.
- Every NDT company must either employ or contract an RPO, full or part-time as appropriate, who reports to the managing director.
- NDT companies should encourage the reporting of near-misses to allow analysis and lessons to be learned.
- NDT companies should ensure that feedback is given to radiographers on incidents that have been reported, for example at safety meetings.
- NDT companies should share information and experiences on incidents with other companies, e.g. through NDT societies or radiation protection societies.
- NDT companies should ensure that all radiographers use collimators or diaphragms for the sources and X-ray units as the default. Any deviation from such practice must have been justified.
- NDT companies should provide all its radiographers with active dosimeters (in addition to the passive dosimeters), equipped with audible alarms and, where applicable, also with visual and/or vibrating alarms.
- NDT companies should ensure that all their radiographers are informed about their occupational doses every monitoring period.
- NDT companies should establish investigation levels, applied for each monitoring period.
- NDT company protocols for establishing the boundary of a controlled area should be based on a balance between the dose rate outside the controlled area, and the ability to maintain oversight of the area and to prevent entry.
- NDT companies should review the reasons why persons are not obeying the warning systems for preventing entry to the work area.
- NDT companies should ensure that their clients, where applicable, inform other workers at the site about the radiation risks associated with the performance of industrial radiography, the purpose and method of the warning systems and, in particular, the meaning of alarm signals.
- NDT companies should ensure that preventive maintenance of industrial radiography equipment is carried out according to the manufacturer's guidelines, and the frequency should be at least once per year, and more frequently when devices are used in harsh conditions.
- NDT companies should perform compliance inspections, with a mix of announced and unannounced inspections. Every radiographer should be inspected at least two times per year. The inspection team should consist of at least the RPO, who provides the radiation protection expertise, and a member of the management team, who would be promoting the importance of safety culture as well as reviewing corrective actions from previous inspections.
- All NDT companies must have an emergency plan and this needs to include the role required in that plan for the radiographers and, if applicable, for the clients. All NDT

companies should include detailed knowledge of emergency procedures and steps required for creating a safe situation in the training given to their radiographers.

- All NDT companies should have an emergency exercise once a year, and review (with the participation of all) the results of that exercise.
- Regulatory bodies need to ensure that as a result of their authorization processes that only NDT companies that meet accepted radiation protection standards (both for normal operations and emergency situations, such as in the IAEA's publication on Radiation Safety in Industrial Radiography, Specific Safety Guide (IAEA Safety Standards Series SSG-11) are permitted to practise industrial radiography.
- Regulatory bodies should consider the benefits of having a recognized qualification in radiation protection for industrial radiographers, and should set minimum standards for RPOs.
- Regulatory bodies should consider developing specific guidelines for safe practice of industrial radiography in their jurisdiction.
- Regulatory bodies should maintain specialized expertise in the area of industrial radiography to ensure effective regulatory activities in this area.
- Regulatory bodies should consider organizing an emergency task group to handle difficult situations that might arise.
- Regulatory bodies need to ensure that they provide clear guidance with respect to setting appropriate dose rates at the boundary of the radiography work area.
- Regulatory bodies should promote a safety culture among NDT companies, encouraging the reporting of incidents within companies and the sharing of lessons learned across companies.
- Client companies, when industrial radiography is being performed on their site, must assume overall responsibility for the coordination of all activities taking place on the site.
- Client companies, who regularly have industrial radiography performed on their site, should perform regular surveys of radiation protection practice at their sites.
- Client companies, who regularly have industrial radiography performed on their site, should consider having a radiation protection advisor or other similar expert to provide specific advice on radiation protection matters.
- Client companies must ensure that they have an emergency plan and that this is discussed with the on-site industrial radiographers.
- Industrial radiographers need to ensure that they receive regular refresher training in radiation protection.
- Industrial radiographers must know and follow their NDT company radiation protection and emergency procedures, and participate in radiation protection training programmes.
- Industrial radiographers must know and have regular contact with their RPO.
- Industrial radiographers must always wear active (with alarms) and passive individual dosimeters, appropriately positioned on the body.
- Industrial radiographers must always use hand-held survey meters.
- Industrial radiographers need to ensure they know their occupational doses.
- Industrial radiographers must report all incidents.

- Industrial radiographers need to ensure that they know their role in emergency situations.

6. CONCLUSIONS

A world-wide survey of occupational radiation protection in industrial radiography was performed over a period of about one year, from mid-2010 to mid-2011. Responses were received from 432 industrial radiographers, 95 NDT companies, and 59 regulatory bodies.

The results from the survey need to be interpreted with caution as the methods for distribution of the questionnaires to radiographers and NDT companies probably means that those that responded represent the better end of the practice spectrum.
Nonetheless, it could be concluded that:

- Initial radiation protection training for radiographers appears to be reasonably well established, but there is room for improvement especially with respect to refresher training. The corresponding regulatory basis needs to be more widely implemented.
- The occurrence of frequency of incidents (accidents, near missed and deviations) is not trivial, and methods such as better incident reporting, analysis, feedback and sharing lessons learned need to be better utilized.
- Collimators and diaphragms are not being used as often as they should be.
- Survey meters are not as widely available or used as they should be.
- Individual monitoring, as reported, is well established, with passive and, usually, active dosimeters. The regulatory basis for active dosimeters could be improved. The establishment and use of investigation levels needs to be improved.
- Warning systems to prevent entry to the work area during site radiography were not always as effective as desired. Better communication between all parties at the site is required.
- Preventive maintenance for the gamma sources, exposure devices and X-ray equipment seem to be well established.
- An industrial radiographer has, on average, the expectation of being inspected by his/her NDT company at least twice a year, and by the regulatory body about once a year.
- Emergency plans were widely prevalent, but there seemed to be some issues regarding specific training for radiographers with respect to emergencies.
- Occupational doses received by radiographers varied considerably, with no correlation with radiographic workload.

In summary, the survey results indicate that there is a need for improved implementation of the radiation protection principle of optimization of protection and safety.

To this end, the results from the survey are being used to: design the ISEMIR database that will be used by end-users to improve their implementation of optimization in occupational radiation protection in industrial radiography; and to develop a “roadmap” tool that enables

NDT companies to assess their own performance in radiation protection against accepted practice.

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