Radiation Protection at Industrial Radiography in Germany Exposures and Unusual Events

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Abstract. In the Federal Republic of Germany safety related events in the use and transportation of radioactive materials as well as in the operation of accelerators are registered. The analysis of these events reveals their causation and allows this conclusions on avoidable errors. In this paper, a special insight is given into events in the field of gamma radiography which is a technical application of ionising radiation for non destructive testing of materials. Conclusions from analysis are drawn. In addition, the occupational radiation exposure of workers is presented taking into account that industrial radiography is performed under particular working conditions with different risks.

1. Introduction

The experience of more than 50 years of a widespread use of radioactive materials in industry, medicine, research and teaching demonstrates good practice. Safety-related events in the use and transportation of radioactive material as well as the operation of accelerators are registered. Although good practice has been established, around 1000 unusual events (incidents) have been registered since 1991. The majority of these cases occurred without any radiation exposure of individuals. One of the main branches in the industry applying radioactive sources is gamma radiography. Industrial radiography is performed under particular working conditions comprising different risks such as

- use of radioactive sources with high activities,
- mobile application on site - often connected with difficult local working conditions,
- no permanent surveillance by a radiation protection officer,
- high work load and time limits for work,
- incidents/accidents can happen in a public domain.

In summary, it can be concluded that the safety culture in this field is less developed than in other industrial branches using radioactive sources.
These characteristics may lead to incidents or deviations from normal working conditions than in other industrial branches using radioactive sources. This is shown in a recent event which happened in Louisiana / USA in June '06 where a radiographer and his assistant may have received an effective dose of approximately 135 and 145 mSv respectively. In this case, it has to be noted that neither the radiographer nor the assistant used a survey instrument to evaluate the source location/position. Moreover, they didn't have had turned on their required alarming rate meter.

The feedback from the analysis of such events in industrial radiography is essential and shall be part of training and education of radiographers. Moreover, the competent authorities should implement a feedback process in their work, e.g. for qualifying the inspections.

In addition, an important issue in industrial radiography applications is the security of the high activity source because of the mobility and the use of the equipment in public domains.

2. Regulations in Germany

2.1 Legal framework

The legal fundament for occupational radiation protection in Germany is the Atomic Energy Act [1]. Subordinated are the Radiological Protection Ordinance [2] and the X-Ray Ordinance [3]. In addition, provisions for outside workers are layed down in an administrative directive focussed on the administrative procedures for radiation passports [5]. Subordinated to the Radiological Protection Ordinance and X-Ray Ordinance are several guidelines and recommendations. They contain requirements for technical equipment, quality assurance, procedures for dose determination and assessment, documentation and information flow between the institutions in charge, etc.. These guidelines and recommendations are primarily addressed to regulatory bodies and dosimetry services.

The European Directive on the Control of high activity radioactive sealed sources (HASS) [7], which lays down requirements concerning the control of high activity sealed radioactive sources, was implemented into German law in 2005. Several frequently used radionuclides in gamma radiography are concerned by these requirements. If the activity of a radioactive source exceeds the limit, given in the directive (i.e. 10 GBq for Ir-192, 4 GBq for Co-60 and 30 GBq for Se-75), the source has to be registered at the Federal Office for Radiation Protection (BfS).

2.2 Federal supervision and Federal State responsibilities

The German governmental system is a federal system with 16 independent Federal States (Länder). The responsibility for authorisation and inspection is assigned to the competent authorities in the Länder by the Atomic Energy Act. The Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) holds the expedience supervision.

The Federal authorities execute mainly the federal supervision and have limited executive power for selected tasks. Regulatory bodies responsible for the surveillance of practical radiation protection are the Federal State Ministries with their subordinated State Offices and regional regulatory authorities.

2.3 Regulatory bodies

The regulatory competence for dose monitoring in industrial radiography lies in the hands of about 120 regional regulatory authorities (“Gewerbeaufsichtsämter”) in the sixteen Federal States. Their local regulators impose licensing warranties and supervise the safety at the workplace or its technical installations. They also licence companies who intend to purchase and use radioactive sources or to apply ionising radiation. Furthermore they determine the necessity for dose monitoring of workers by an appointed dosimetry service.

2.4 Monitoring situation in Germany

The supervision of occupationally exposed persons is defined in the above mentioned law and ordinances. Monitoring of occupationally exposed workers covers in general monitoring of the workplace and individual monitoring. The legal demand is the estimation of the effective dose in the use of ionising radiation to control compliance with legal limits for the individual exposure. In Germany, three approved dosimetry services (handing out also the authorised personal dosemeters) exist for the official assessment of external exposures. Appointed by a Federal State the dosimetry services are responsible for all resident companies. Film badges are used as authorised dosemeters supplemented by special solid state dosemeters. The doses are determined monthly.

In addition to the annual dose limits as demanded in the Guideline 96/29 EURATOM, German regulation includes a limit of 400 mSv for occupational lifetime dose. Both, the decentralised monitoring system and the lifetime dose limit require an uninterrupted control of occupational radiation exposure, independent of place, time and type of exposure. This is the task of German Radiation Protection Register of the Federal Office for Radiation Protection (BfS), where the monthly dose values are assembled to individual dose histories.

3. Occupational radiation exposure

In 2004, official dose monitoring for external radiation exposure was performed on about 314,000 workers in some 27,000 facilities. About 75 % of the workers are employed in the medical sector, the others in the nuclear sector, the general industry as well as in research and education. Only about 45,000 workers are de facto radiation exposed, i.e. they receive doses above the minimum detection level of 0.05 mSv. For this group, the average effective dose was 0.8 mSv in 2004.

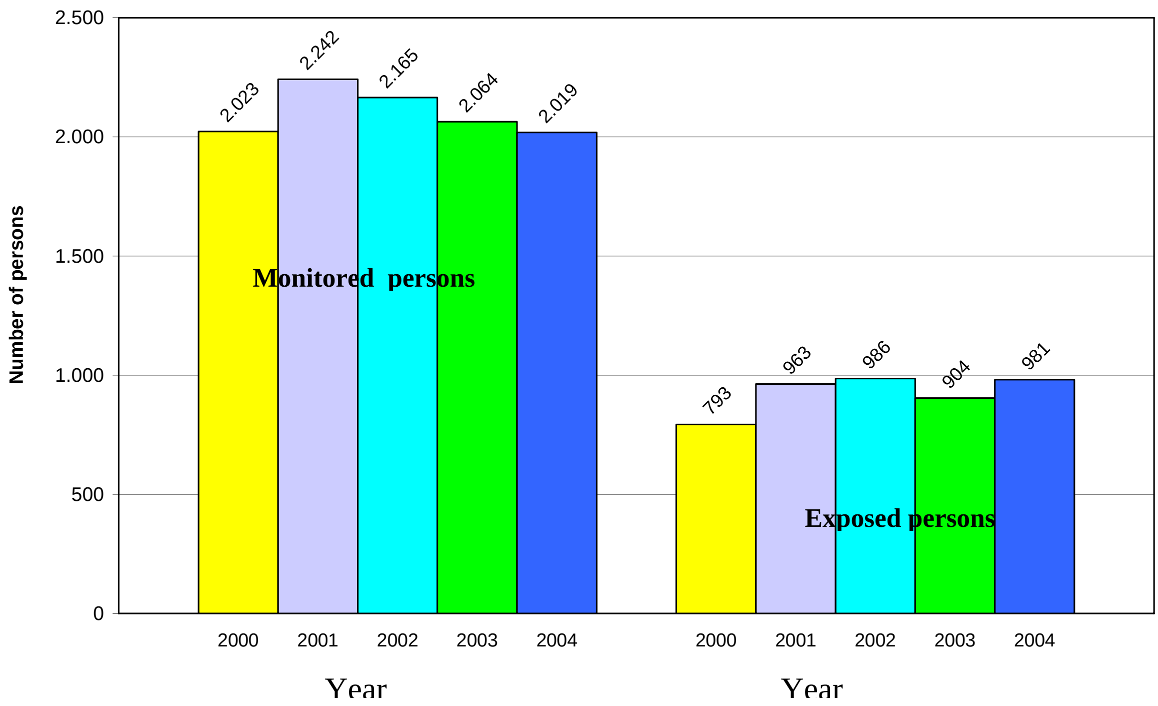

Figure 1: Number of monitored and exposed workers in occupational category „Radiography with radioactive sources or X-Ray“ in Germany from 2000 – 2004

From the perspective of radiation protection, radiographers are the “critical group”. Some more than 2000 workers are registered in the category “industrial radiography” (Figure 1). The mean annual effective dose of industrial radiographers is about three times higher than the grand mean value. A reduction of the average effective dose from 2.9 mSv in the year ffective dose (mSv)2000 to 2.3 mSv in 2004 can be stated (Figure 2). During the same period the average annual effective dose of all occupationally exposed workers decreased in Germany from 1.2 mSv to 0.8 mSv. Thus, the declining dose trend in industrial radiography is in concordance with the general trend, albeit to a smaller extent.

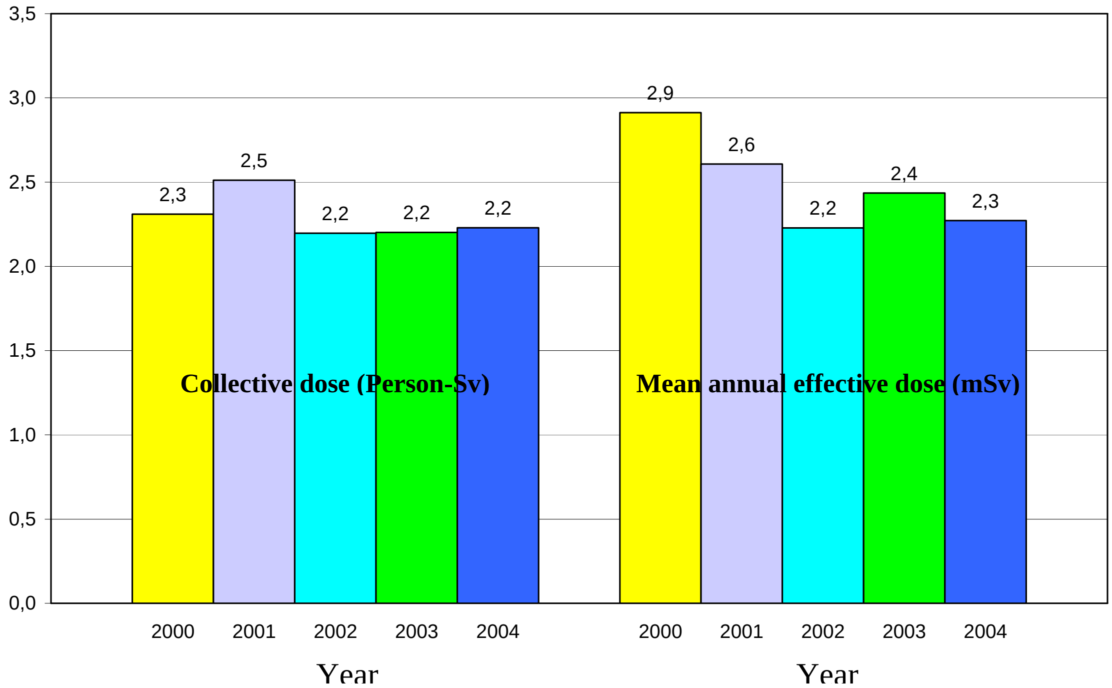

Figure 2: Collective dose and mean annual effective dose of workers in occupational category „Radiography with radioactive sources or X-Ray“ in Germany from 2000 – 2004

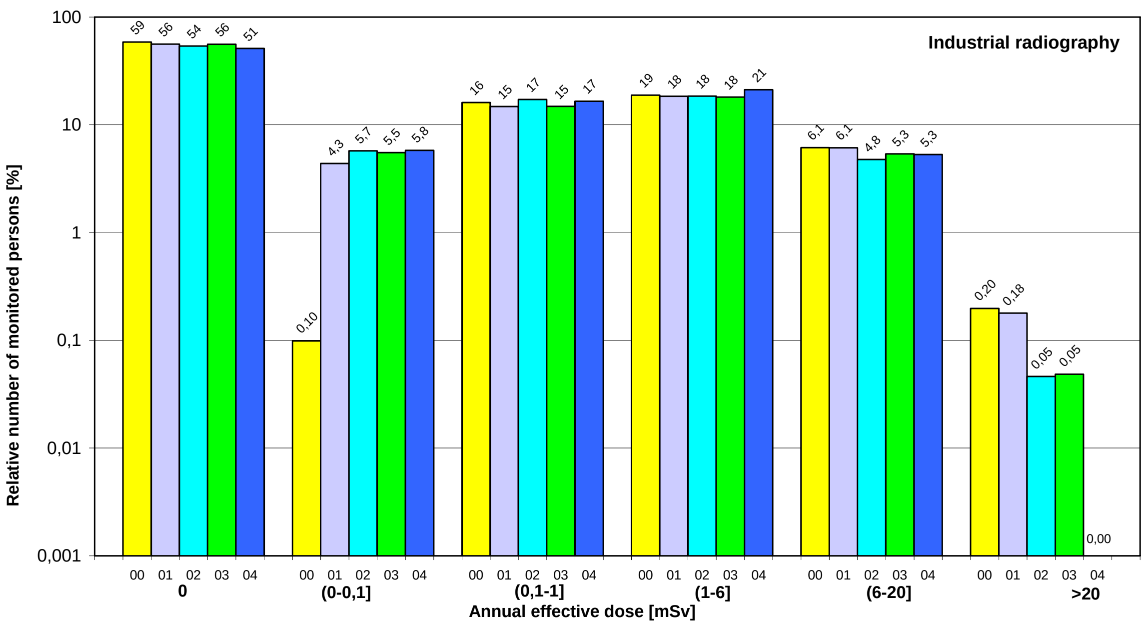

Figure 3: Distribution of annual effective doses of monitored workers in occupational category „Radiography with radioactive sources or X-Ray“ in Germany from 2000 – 2004

In the non-medical sector including the industrial radiography some changes can be seen in the dose distributions (Figure 3 and 4). The decrease in the number of unexposed workers can be explained to a certain extent by the introduction of the new detection level for dosemeters: after being lowered from 0.1 mSv to 0.05 mSv, numerous workers appear now in the group of exposed workers, whereas before, their doses had been rounded to zero.

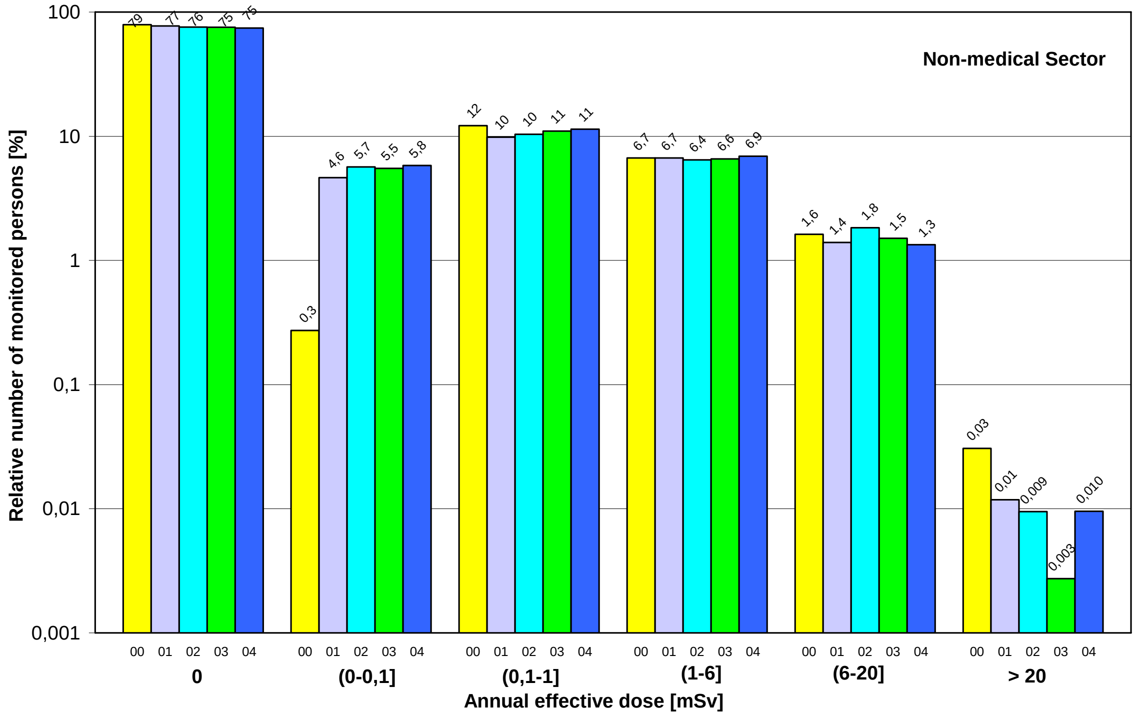

Figure 4: Distribution of annual effective doses of monitored workers in the non-medical sector in Germany from 2000 – 2004

After the implementation of the amended radiological protection ordinance with its new annual dose limit of 20 mSv/a, a decrease in the number of dose limit exceeding is obvious. The few remaining cases of overexposures are seldom. They appear only stochastically and in the order of magnitude of one among 10,000 workers per year. This holds for non-medical sector including the industrial radiography. About 25 % of all workers in the non-medical sector receive measurable doses, in the industrial radiography 50 %. The shape of the dose distributions is similar for both exposed groups, although there are higher frequencies especially in the dose interval from 1 - 6 mSv. A general shift towards low doses values cannot be stated for the five year period.

Apart from the statistical evidence of the recorded data, it should be taken into account that possibly not all exposures have been measured, reported or recorded. Also, a distinction between fixed and mobile radiography is not possible. The data may therefore underestimate the exposure of those radiographers who work only with mobile equipment. Furthermore, the given data refer solely to person doses. Data about measured partial body exposures are not available.

These statistical findings do not appear dramatic and there is no reason to be generally alarmed. But it appears that there is room for optimisation of protection. This applies especially to the reduction of doses as well as to steps in order to reduce the number of incidences.

4. Unusual events – statistical investigations

4.1 General data

Exceptional events (incidents) in the use of radioactive material, ionising radiation and during transportation have to be registered by the competent authority in the Federal States and have to be reported to the BMU. The analysis of the registered events, feedback is performed by the BfS. Currently, no unified scheme and no declaration criteria exist for this registration. Therefore information is often insufficient for detailed analysis. The registration of safety relevant events in the use of ionising radiation in Germany is demanded by a ministerial circular letter addressed to all competent authorities summarizing the following information:

- type of safety relevant event,
- place, date, time,
- extent of the event (individuals, real assets, environment),
- miscellaneous data.

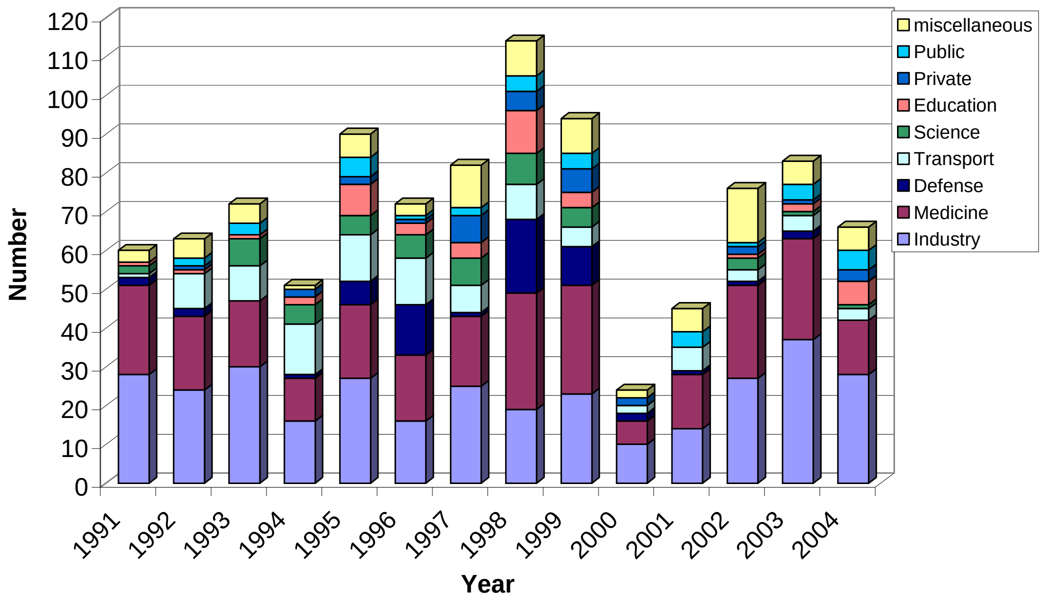

Figure 5: Incidents in Germany – Overview

In Germany, the competent authorities reported 992 incidents in the years 1991 – 2004. Detailed data are shown in Figure 5. 33 % of the radiation incidents occur at industrial and 27 % at medical workplaces. In some years there is also a marked amount of incidents in abandoned military areas (6 %) or in the transportation sector (10 %). In comparison, incidents in other sectors happened less frequently:

- at workplaces in gamma radiography 4 %,
- at workplaces in science 5 %,
- in education areas 4 %,
- at public locations 4 % and
- at private locations 3 %.

Until 1999, the total number of radiation incidents had slightly increased from about 70 to about 100 per year. In the year 2000 a significant decrease to less than 30 events per year occurred, than the number of radiation events has been increased again. The conspicuous decrease in 2000 might be caused by administrative confusion on the users´ side. Due to the revision of Radiation Protection Ordinance [2] to adopt the Council Directive 96/29/ EURATOM [4]. Because many fundamental changes in German regulations took place, several users probably did not report incidents before the new regulations had been completely implemented.

4.2 Incidents in gamma radiography

In the years 1991 to 2004, in total 35 events happened at gamma radiography sites in Germany, constituting 11 % of all incidents in the industrial sector. Annual rates for both sectors are plotted in Figure 6.

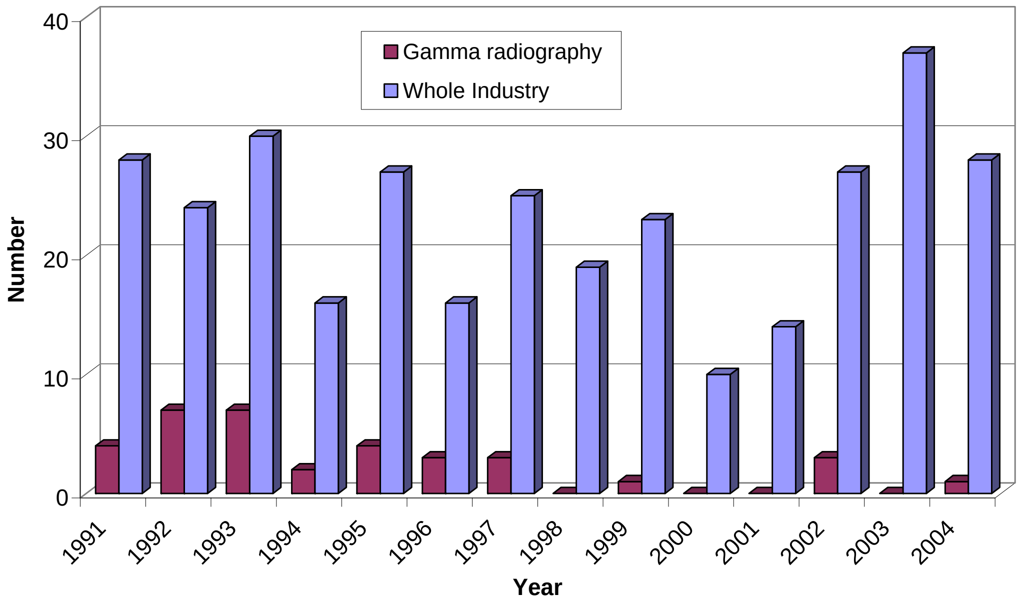

Figure 6: Incidents in Gamma Radiography in Germany - Overview

4.3 Radionuclides and activities

Radionuclides frequently used for gamma radiography are Iridium-192 (300 – 500 keV), Cobalt-60 (1.1 to 1.3 MeV) and recently Selenium-75 (100 to 400 keV). Also Ytterbium-169 (50 to 310 keV) and Thulium-170 (50 to 85 keV) are used in few applications.

Because of the lower energies of Ir-192 and Se-75 high activities are used to reduce the exposure times which are necessary to get a sufficient image. Long exposure times would extend also the duration of the work and would require safety precautions to be enforced for longer periods.

The used activities are in the following ranges **Fehler! Verweisquelle konnte nicht gefunden werden.**]:

C-60	0.41	to	7.4	TBq
Ir-192	0.19	to	7.4	TBq
Se-75	0.30	to	3.0	TBq
Yb-169	0.093	to	0.37	TBq
Tm-170	0.74	to	7.4	TBq

Figure 7 gives the radionuclides involved in the reported incidents with gamma radiography equipment and the activities. Nearly half of the incidents happened with devices equipped with Ir-192 sources with activities between 0.1 and 4 TBq. Se-75 and Co-60 were involved less frequent. Their frequency lies below 10 %. A considerable contribution (37 %!) comes from events without mentioning the radionuclides. In such cases no detailed information was submitted by the competent authorities.

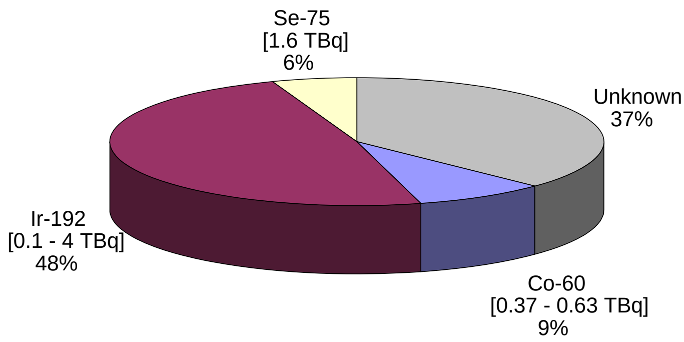

Figure 7: Nuclides and activities at incidents

4.4 Analysis of causes

The causes for incidents can be diverse. However, they can be categorized into two major classes: technical failures (29 %) and human malpractice (65 %). Only in 6 % of the events the reason could not be identified.

Technical failures are material fatigue, wear and tear, constructional faults, breakdown of safety arrangements etc. These failures lead to events like

break of source holder	3 %,
malfunction of magnet	9 %,
malfunction of source tube	6 %,
malfunction of source wire	6 %.

The category human failures frequently contains breach of operation instructions, work regulations or radiation protection provisions, defaulted controls, wrong decisions or negligent actions. However, the analysis of the incidents showed that the cause of the events could not in any case be classified clearly into one of the both classes.

In 34 % of the events, disregard of regulations or instructions was identified as the most frequent cause. More details can be seen in Figure 8.

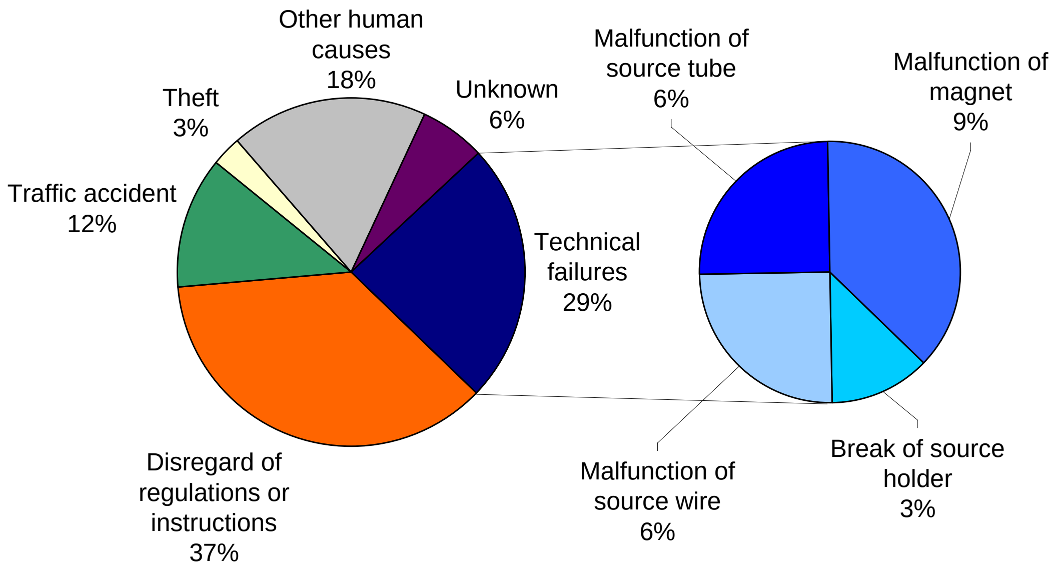

Figure 8: Causes of incidents - Overview

4.5 Radiation exposures

Frequently, human malpractice was recognized as the cause for incidents. A specific issue

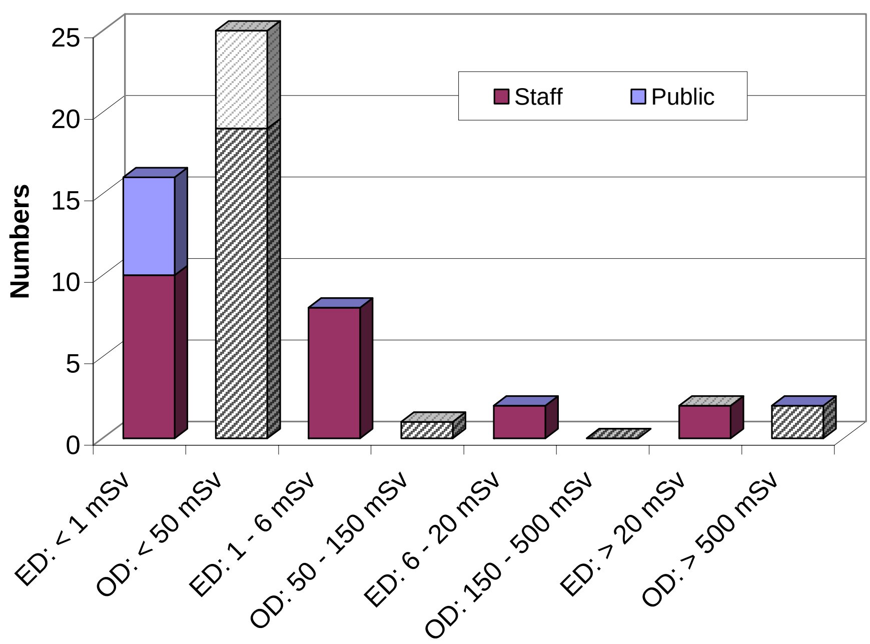

Figure 9: Effective dose (ED) and organ dose (OD) of exposed persons

are the so-called reflex actions which are mostly connected with high exposures for the radiographer. In the considered period of time, 35 workers and 6 persons of the public domain were exposed. In two events the effective dose was higher than 20 mSv (max. 60 mSv) and in two further events partial body doses of more than 500 mSv were registered. Figure 9 gives an overview.

5. Case studies

Three representative cases are presented in the following table.

	Case A	**Case B**	**Case C**
History	Whilst the use of a gamma radiography device the magnet holder of the source unsoldered and the complete source fell from 1.5 m down to earth, where it broke. Consequently the source could not be removed immediately.	A collimator of a gamma radiography device was not fixed correctly. At the use of the device the collimator took off and bent off the source tube, so that the source wire could not be moved. The worker bent the tube manually to allow the source wire to move again.	At the use of gamma radiography the temporary controlled area was not correctly marked off.
Consequences	• The workers succeeded to bring the source back after some trials. • Two persons received effective doses of 2 and 6 mSv and a hand dose of 3.6 Sv. • The device was send to the manufacturer for maintenance.	• One person received an effective dose of 1.2 mSv and a hand dose of 9 mSv. • It was found out that the worker was not adequately trained. • He was prohibited to work as occupationally exposed person until he had passed another trainee.	• Persons working nearby at about 1 m distance (member of public) received an effective dose of 40 µSv. Luckily the persons worked in the radiation shadow of the investigation object. • The authority issued a caution to the responsible radiation officer.
Lessons learned	Manufacturers have to be informed about technical problems in order to improve the design of the device.	Training and education has to be intensified. Training centres should be provided with information about common human malpractices.	Training and education concerning the legal basis and main tasks in radiation protection has to be intensified.

6. Conclusions

With a careful analysis of incidents common causes can be identified. The conclusions from these investigations has to be implemented into practical work. Thereby, safety will be increased and the reoccurrence of unusual events could be minimised.

Because disregarding of regulations and instructions is the most frequent human error, training and education should be intensified in Germany in the future.

A difficult and often discussed tool is the administrative fine. Certainly, the punishment by fine has an educational effect but it is supporting the trend to conceal of incidents especially in case of marginal events.

Several technical failures show that a feedback from unusual events should be made available to manufacturers. It will enable manufacturers to continuously improve the quality assurance and the design of their devices.

The high potential risk for exposure of workers and public connected with high activity sealed radioactive sources emphasises the necessity for enhancing the control of such sources.

In order to minimise risks from orphaned gamma radiography sources and to share lessons learned from ionising radiation incidents, it is an important task to improve international cooperation. With the project EURAIDE, first steps on the European level have already been undertaken. This project should be continued.

References

[1] Gesetz über die friedliche Verwendung der Kernenergie und den Schutz gegen ihre Gefahren (Atomgesetz) of 15.07.1985 (BGBl. I, p. 1565), last amendment of 12.08.2005 (BGBl. I, p. 2365)

[2] Verordnung über den Schutz vor Schäden durch ionisierende Strahlen (Strahlenschutzverordnung – StrlSchV) of 20.07.2001 (BGBl. I, p. 1714 and BGBl. 2002 I, p. 1459), last amendment of 01.09.2005 (BGBl. I, p. 2618)

[3] Verordnung über den Schutz vor Schäden durch Röntgenstrahlung (Röntgenverordnung - RöV) of 08.01.1987 (BGBl. I, p. 114), last amendment of 30.04.2003 (BGBl. I, p. 604)

[4] Allgemeine Verwaltungsvorschrift zu § 62 Abs.2 Strahlenschutzverordnung ("AVV Strahlenpass") vom 20.07.2004 (BAnz. Nr. 142a vom 21.07.2004 S. 1)

[5] Council Directive 96/29/EURATOM of 13.05.1996 (OJ L 314, 04.12.1996, p. 20)

[6] Categorization of radioactive sources, IAEA Safety Standards, Safety Guide RS-G-1.9, International Atomic Energy Agency, Vienna 2005

[7] Council Directive 2003/122/EURATOM, 22.12.2003 (OJ L 346, 31.12.2003, p. 57