Estimation of personal dose while processing NORM-contaminated metal scrap

Rainer Kreh[a], Shaheen Dewji[b]

[a]Siempelkamp Nukleartechnik
Krefeld, Germany

[b]University of British Columbia
Vancover, Canada

Abstract: In 1998, Siempelkamp Nukleartechnik started to operate a special melting shop at the Krefeld site. Contaminated metal scrap resulting from decommissioning of natural oil and gas production plants, the mining industry, fertilizer production and groundwater extraction is melted in order to transfer the contamination such as mercury and NORM into the slag and the dust, enabling the decontaminated metal to be recycled. Usually, NORM contamination results from the radium decay chain ^{226}Ra and/or from the thorium decay chain. According to the German radiation protection ordinance, based on the Euratom radiation protection recommendations, an observation of working areas is necessary, if the dose exceeds 1 mSv/a, caused by natural radioactive materials during the total disposal process. To determine the worker doses, measurements were made in 2005 in various ways. Besides long term TLD dose measurements, workplaces were measured with electronic dosimeters for 24 h periods. Additionally the workers wore personal dosimeters during their working time. The working time at each workplace was documented to be able to weight the daily dose for the specific workplace. Contrary to the dose from external radiation, a former study has shown that incorporation is negligible. Due to the possible mercury air concentration, all of the workers wear breathing apparatus with a filtration factor of 99.997%. No radioactivity has been detected by urine analyses. The resulting personal doses calculated from the measurements are approximately 0.08–0.3 mSv/a, which is in the range of previous results, ascertained only by TLD dose measurements.

1. Introduction

In a special melting plant at the Siempelkamp site in Krefeld called GERTA, which started operation in 1998, contaminated metal scrap is treated to remove chemical or radioactive contamination. The material mainly comes from decommissioning in the oil and gas production industry [1, 2], see Fig. 1. The chemical as well as the radioactive contamination appears in the scale inside pressure pipes, where the predominant process is the precipitation of the radioactive isotope ^{226}Ra. After a short period, about a month, the daughter nuclides ^{218}Po, ^{214}Bi and ^{214}Pb are found to be nearly in equilibrium to ^{226}Ra. The activity concentration found in the pipe scale is up to 1 000 Bq/g. Related to the total amount of material and a scale ranging from 0.5 to 5% this gives a specific activity of 50 Bq/g in maximum.

Another kind of material has its origin in the production of tungsten welding electrodes and filaments for the light bulb production industry. To improve the thermal and luminous efficiencies of these materials, thorium at 2–4% is added to the tungsten. The resulting activity concentration of ^{232}Th is found to be in the range 12–15 Bq/g. The treatment of these materials and the generated waste leads to a exposure of workers, which should be analysed according to the dose-limits given in Refs [3, 4].

2. Motivation for this study

About 50% of the incoming scrap is contaminated only with chemical substances. The other 50% is also (or only) contaminated with NORM. The Euratom radiation protection recommendations [3] and the German Radiation protection Directive [4] require the monitoring of radiation doses if the dose, during handling the waste, is likely to be more than 1 mSv per year for any person. To ascertain, if this limit is exceeded in the melting shop, a lot of various dose measurements were necessary.

FIG. 1. Example for contaminated pressure pipes from the oil and gas production industry and waste material from the tungsten welding production industry.

3. Measurements

Most of the measurements were carried out in 2005 during industrial training at Siempelkamp Nukleartechnik [5]. To get an overall view of the exposure conditions, this investigation was aimed at estimating workplace exposure levels and not the dose actually received by workers. First the exposure conditions and the exposure time were determined for each workplace. Next, exposure measurements were carried out in different ways to get an average exposure for each workplace. In particular, stationary measurements with thermoluminescent dosimeters (TLDs) and electronic dosimeters (Fig. 2) were carried out, as well as direct dose rate measurements and measurements of personal dose.

FIG. 2. Measuring equipment: electronic personal dose meter (EPD), thermoluminescent dosimeter (TLD) (installed at shear exit) and area dose rate meter

3.1. Stationary dose measurements

To obtain an accurate stationary reading during melting and dismantling operations in the GERTA plant, nine dosimeters were positioned and monitored on a daily basis during each of the melting and dismantling operations. The workplace EPD (electronic personal dose meter) provided the most complete data set for a daily resolution of the workplace dose. The EPDs were placed in the following locations:

– Outdoor storage
– Thermal cutting room
– Shear control balcony
– Shear bin (exit materials)
– Intermediate storage
– Melting oven console

– Furnace control room
– Pouring/slag removal
– Filter dust (outdoors)

TLDs are routinely placed in five locations throughout the GERTA facility and are replaced approximately every three months. These dosimeters provide accurate data over the three month period. For this investigation, these data are the most accurate for calculating the annual dose, as they are obtained over a longer time frame. The TLDs are positioned in the following locations:

- Melting oven, furnace control desk
- Intermediate storage
- Shear control balcony
- Thermal cutting room
- Shear exit bin

3.2. Direct dose measurements

Direct dose measurements were taken for all critical work areas during a dormant period, when neither dismantling nor melting was occurring. These dose measurements were taken for a period of approximately one hour, from which the dosimeter provided the average dose rate in this time period, which is equal to the total background dose for the GERTA facility. Direct dose measurements were taken in the following work areas:

- Shear/thermal cutting room
- Melting hall
- Pouring and slag removal
- Outdoor storage

The measurements show for most of the tested areas a natural background dose rate for the Siempelkamp site in Krefeld of about 0.10–0.11 μSv/h, which leads to a daily dose of approximately 2.5 μSv. This background dose was used for correction of TLD or EPD dose measurements. Data were not gathered at the site of the filtration system since previous studies had shown the dose rate in this location to be negligible and undetectable, because the filtration system mainly contains lead and polonium isotopes such as ^{210}Pb and ^{210}Po.

3.3. Personal dose measurements

In addition to stationary EPDs, the workers were instructed to wear dosimeters during their shift-work while dismantling and melting NORM materials. In addition to EPD dose monitoring, the workers recorded approximately how much time they spent in each of the primary working areas.

4. Measurement results

Data were recorded for two measurement campaigns involving dismantling and melting of NORM materials. The third measurement campaign involved only the dismantling of NORM materials over a two-week period. From the different sources of data, the dose rate (μSv/h) was calculated for each of the work areas or activities in the GERTA plant. Each method gave a different result, because each was only accurate for the given timeframe, and some methods often did not provide information for the full working area for GERTA.

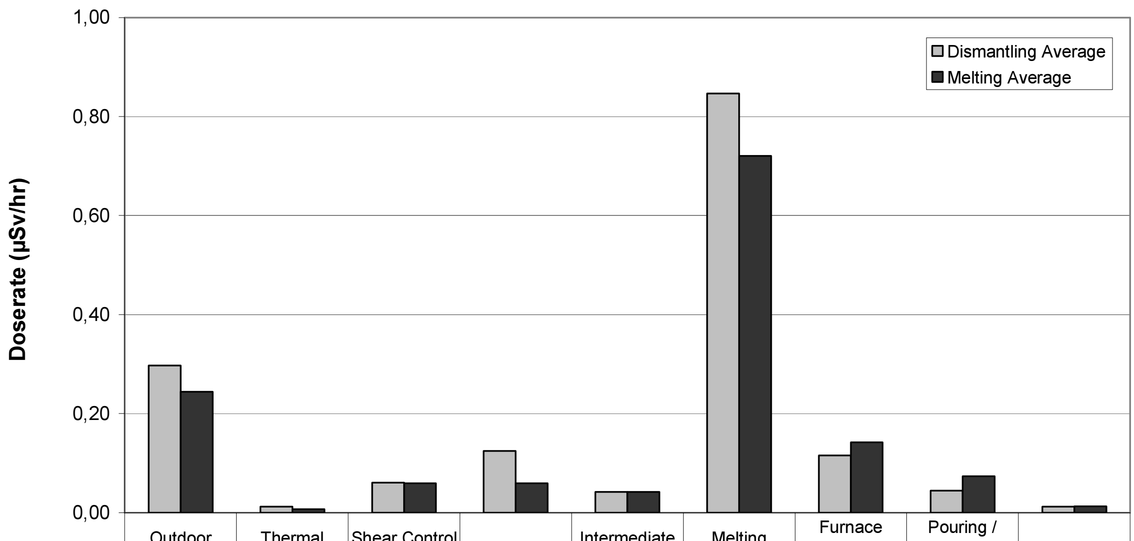
4.1. Results of stationary dose measurements

The data from the workplace EPDs were recorded on a daily basis to determine the dose rate, but a weighted average was used over the accumulated time frame for the melting or dismantling campaign. Therefore, in determining the overall average for the dose rate of a certain work area, the campaign with the longest duration of exposure gave a higher accuracy than those with shorter recording periods.

During dismantling, the primary work areas were the outdoor storage, thermal cutting, shear control balcony, and shear exit. The remaining workplaces were not used since melting was not occurring during this time. For the work areas where dismantling occurred, the outdoor storage yielded the highest dose rate of 0.30 µSv/h, followed by the shear exit bin (from which all the dismantled materials exit) at 0.12 µSv/h. The thermal cutting room was equal to the background dose of GERTA.

Melting activities are primarily in the furnace hall, the outdoor filtration area, the pouring and slag removal area, and outdoor storage area. Following the trend of the dismantling data, the furnace hall had the highest average dose rate of 0.72 µSv/h. Then the outdoor storage area had the next highest dose, similar to the dismantling data trend. This knowledge is rather trivial, because the primarily dose rate is not produced by the handled material, but much more by the stored waste. The high dose in outdoor storage does not merit concern for the workers, since the time they spend doing outdoor work is significantly less compared with their other activities within the GERTA plant. The location where pouring and slag removal takes place gave an average value of 0.07 µSv/h, and the location where the filter dust is packed contributed a negligible dose, since the bulk of the active materials is deslagged.

For the workplace EPDs, the comparison between the melting and dismantling is shown in Fig. 3. Although, due to the dose, only the outdoor storage, intermediate storage and furnace control room are independent of the melting and dismantling processes, the thermal cutting room, shear control balcony, intermediate storage and filter dust locations also appear to be equal in dose rate each other, regardless of the radioactivity. During dismantling, the shear exit has a higher dose rate than when not in use during melting. It is interesting that the furnace area was slightly lower during melting than while not in use during dismantling. The reason for this was the presence of drums with floor sweepings with higher activity, i.e. residues from the shear and the thermal cutting, stored in the furnace room during the dismantling campaign — they raised the dose rate. Also, the furnace control/computer room was close to the floor sweepings — the dose rate here was higher than during normal conditions, in the absence of these materials.



	Outdoor storage	Thermal Cutting	Shear Control Balcony	Shear Exit	Intermediate Storage	Melting Furnace	Furnace Control Room	Pouring / Slag Removal	Filter Dust
Dismantling Average	0,30	0,01	0,06	0,12	0,04	0,85	0,12	0,04	0,01
Melting Average	0,24	0,01	0,06	0,06	0,04	0,72	0,14	0,07	0,01

FIG. 3.Comparison of workplace dose measured by EPD for melting and dismantling

Radiation measurement using TLDs is a regular practice at GERTA. Over the past six years, TLD reports have been analysed to get a weighted average (dependent on exposure time) for each of the five areas (see Section 3.1). They give a comprehensive, and perhaps the best estimate of, the dose rate for GERTA over a longer time period, in this case three months. To be able to calculate the workplace dose from the TLD dose, the average exposure time at this workplace is needed. Therefore the workers note the time for each activity in which they were involved in an exposure area. From these notes, an average time spent was calculated and allocated to this special workplace. Fig. 4 shows the percentage of the time spent in the melting and the dismantling areas.

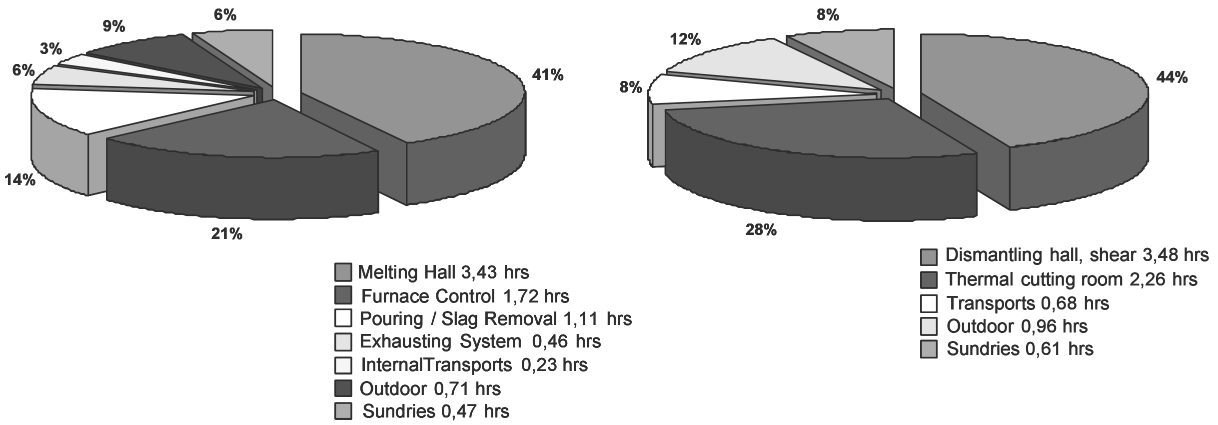


FIG. 4. Time spent for various activities in the melting area (left) and the dismantling area (right)

Fig. 5 shows a comparison between the measured area dose and the time weighted area dose. As expected, the working area around the furnace control gave the highest correlation. This is because the distance from the TLD to the contaminated material is similar to the distance in the real workplace. For the workers at the furnace control, pouring and deslagging, the working distance is less than while dismantling at the shear. Although the measured dose is nearly as high as at the furnace, the time weighting leads to the lowest workplace dose, because the time spent at the intermediate storage is very short.

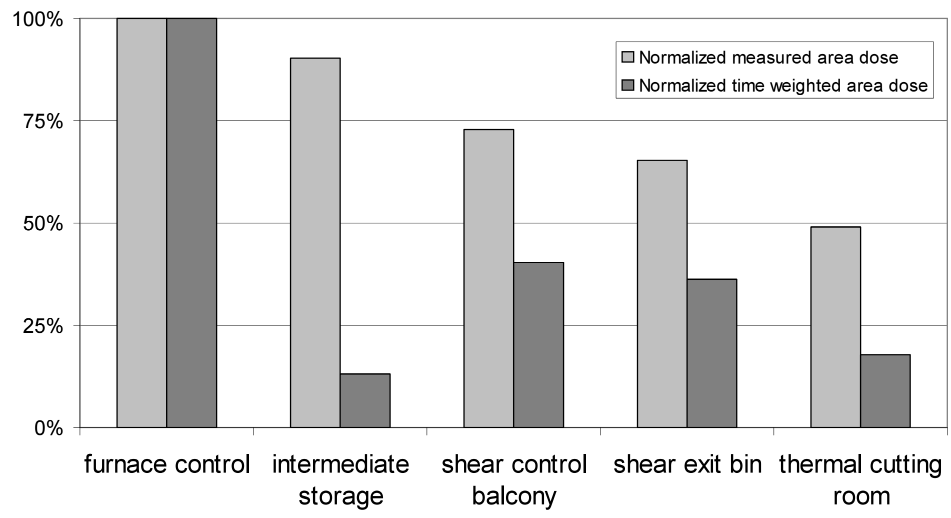


FIG. 5. Comparison of weighted and unweighted normalized area doses for different workplaces

Fig. 6 shows the dose timeline for the two main working areas: the furnace operation platform and the shear. As can be seen from the fitted curves in the diagram, the dose rate of the melting process follows the dismantling process with a time gap. Additionally the dose near the furnace is much higher than during dismantling. This can be explained by two effects. One is that the worker is closer to the contaminated material during slag removal and slag packaging than during dismantling. On the other hand the activity concentration associated with the melting process is much higher in the slag than in the incoming and dismantled material. Note that the dose rate in Fig.6 consists of raw data from the TLDs and is only qualitative. The data are not corrected for background or work time.

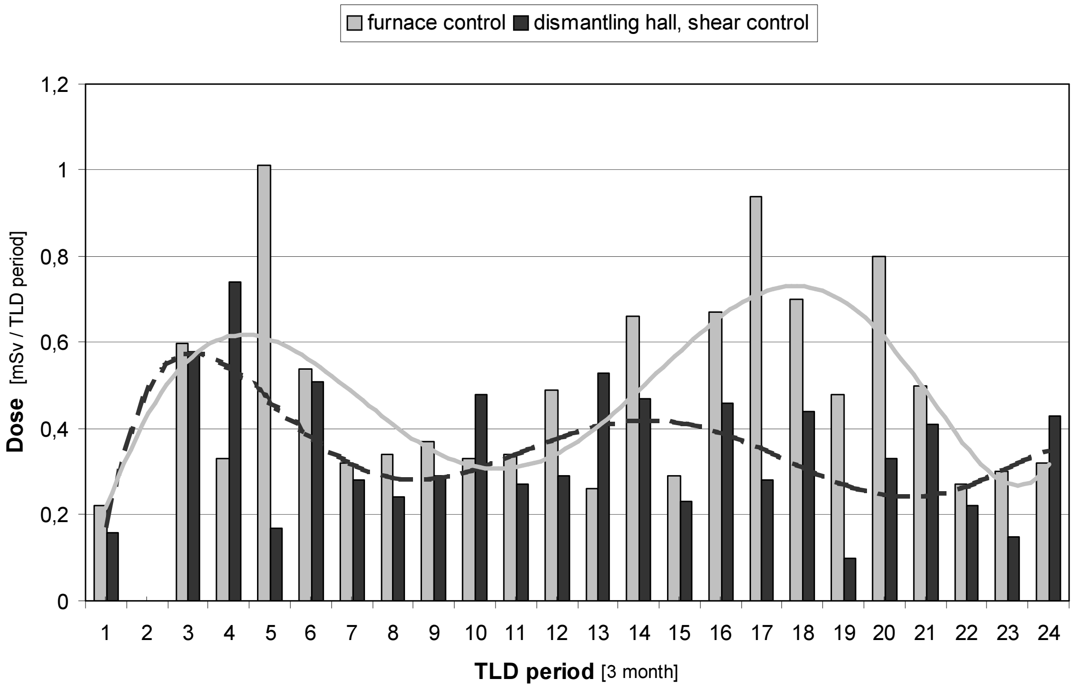


FIG. 6. Comparison of melting and dismantling over a period of 6 years. This is TLD raw-data not background corrected and not corrected for one shift.

4.3. Results of personal dose measurements

From the worker notes, the dose per shift and the average time spent doing each activity for dismantling and melting as mentioned above was provided for the duration of the three campaigns. From these notes, the overall average dose per shift for dismantling was 2 µSv/shift or 0.25 µSv/h. The overall average dose per shift for melting was 4 µSv/shift or 0.5 µSv/h. Assuming alternating melting and dismantling campaigns of equal time segments, an average dose rate for the GERTA plant is calculated to be 0.38 µSv/h. However the doses recorded for dismantling were averaged over a shorter period, and hence a smaller amount of data contributed to the accuracy of the dismantling compared with the doses recorded for melting.

In the same way that TLD work time was weighted, the workers' directly measured doses were also weighted by the approximate time spent at each activity. The breakdown of their work schedules per shift, on average, is shown in Fig. 4 for dismantling and melting. Dismantling activities are dominated by work at the guillotine shear and thermal cutting hall, whereas the melting activities are dominated by work in the furnace room and the furnace control panel.

The dose rates were statistically extrapolated from the workers' EPDs. This method was a crude method as it assumed that the dose rate for a single worker per shift was the same for each activity. By averaging the dose rate with the time spent for a specific activity in that shift, and then averaging the data over all shifts, a very crude dose rate for each work activity was obtained. Compared to the workplace EPDs, direct dose measurements and TLDs, this method is a statistical extrapolation, and its values are rather inaccurate in conveying the dose rate in the GERTA facility. However, since it is not possible to determine exactly what fraction of the recorded dose was due to any specific activity during the shift, the dose was multiplied with the fraction of the shift spent at a specific activity in order to obtain the dose rate.

5. Comparison of the different methods of data acquisition

It is possible that the different methods of measuring workplace doses lead to different results. Workplace EPDs and TLDs are fixed in position, whereas the workers' EPDs during the working time are at various distances to the contaminated material. As an example, Fig. 7 shows a comparison of three workplaces during dismantling. The doses for the shear and the intermediate storage are all in a small range, with a maximum deviation of 25 %. The discrepancy of the measured doses in the thermal cutting room shows very impressively the result of significant variations in distance to the contaminated material.

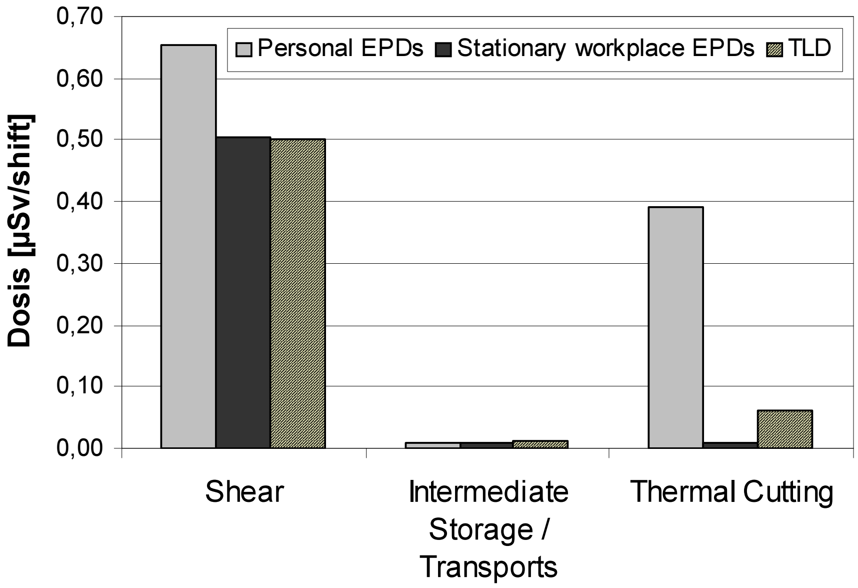


FIG. 7. Comparison between the different measuring methods

6. Conclusion

Approximately half of the activities in GERTA are spent handling NORM, the other half dealing with toxic contaminants, primarily mercury. Based on these annual time statistics, and the average percentage of time spent at each activity (recorded from the worker notes), in addition to the dose rates acquired from the direct dosimeter readings, workplace EPDs, and TLDs, the annual dose per worker can be calculated (Table 1). Except in the melting area, the TLDs gave the highest calculated annual dose. It is interesting that the TLD measurements give nearly double the doses given by the personal EPDs, which should give the most precise total dose.

From this point of view, the TLDs gave a sufficiently conservative dose with a maximum dose of approximately 0.3 mSv/a for the working areas in GERTA. Assuming they can be positioned in a practical way according to the working conditions, for instance a measuring point at an average working distance to the contaminated material, TLD measurements are easy to carry out and give a good conservative estimate for the real working situation.

All the calculated doses in Table 1 are specified without any value of uncertainty. The reason is that there are many different sources of uncertainty, besides those associated with the measurements themselves, in the various measuring methods and they are not clearly defined up to now. In detail they are:

- The frequent changing of workplaces when the dose rate is very low makes it difficult to assign a dose for a single workplace.

- As mentioned before, it is not correct to assume that the dose rate for a single worker per shift is the same for each activity.

- Averaging the dose of the workplace EPDs, and more especially the TLDs, and weighting by the working time reduces the effective dose. (This effect was already taken into account)

- Storage of floor sweepings in the furnace hall lead to an overestimation of the workplace dose for this area.

Nevertheless the results gained up to now show that the NORM processing activities in the GERTA plant result in doses to workers well below 1 mSv/a. The investigation will be continued during the next NORM campaigns in GERTA.

TABLE 1. DOSES ASSOCIATED WITH THE DISMANTLING AND MELTING AREA

Measuring method	Anual effective dose (mSv)		
	Dismantling	Melting	Total
Personal EPD	0.04	0.10	0.14
Stationary EPD	0.03	0.26	0.29
TLD	0.07	0.21	0.28

REFERENCES

[1] QUADE, U., KREH, R., MÜLLER, W., Recycling of radioactively contaminated scrap from the nuclear cycle and from natural sources, European Metallurgical Conference, Hannover, 2003

[2] QUADE, U., MÜLLER, W., Melting of NORM-scrap from various industries, ICEM ’05 (Proc. Conf. Glasgow, 2005).

[3] Amtsblatt der Europäischen Gemeinschaften. Richtlinie 96/29/Euratom des Rates vom 13. Mai 1996, L 159 (1996)

[4] Bundesgesetzblatt BGBl. III 751-1-8, Verordnung über den Schutz vor Schäden durch ionisierende Strahlen (Strahlenschutzverordnung - StrlSchV), 2001

[5] DEWJI, S., Irradiation dose of employees caused by handling NORM Materials, Report of industrial training. Krefeld, 2005.