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RADIOACTIVITY IN SCRAP

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1. Introduction
Metal scrap is a valuable and very important material which plays a fundamental role in our modern industry. Extensive measures have therefore been taken to ensure the continuous quality of the scrap and the new metal that is manufactured from it. Product quality is one of the main reasons why the metal processing industry has reacted very sensitive to detection of radioactivity of various origins in scrap.

The first reports on radiation sources mixed in scrap loads and naturally occurring radioactive material (NORM) as contamination on scrap metal surfaces can be found in the early 1980's [1]. There has since been an increasing number of reports, partly due to the fact that people became more aware of the possibility of radioactivity in scrap and of its dangers, partly due to the fact that more measuring devices were installed. Several years passed before the problem was tackled in Europe, but meanwhile there is a dense net of measurement facilities at borders as well as at foundries and scrap yards in many countries. While this initially led to an even steeper increase in the number of radioactivity alarms, now there seems to be a slight decrease in incidents, probably because more effective measures have been widely implemented to prevent radioactivity from entering the scrap already at the place of origin.

Radioactivity in scrap has also been a major issue in Germany for several years. Although Germany's scrap export exceeds the import, the import of scrap still amounts to more than one million Mg per year. Radioactivity has been found mainly in imported scrap in Germany. A number of detections have been reported in those German Federal States where there are metal processing industries. Although there have only been very few incidents the consequences of which might have become serious if no countermeasures would have been taken, meanwhile all foundries and all larger scrap yards are equipped with entrance monitors.

This paper gives a short overview of the current situation in Germany and analyses briefly the possible radiological consequences. The whole subject has been thoroughly investigated on behalf of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety [2]. This paper does not deal with scrap that is released from nuclear installations like nuclear power plants where scrap and other materials are cleared if they comply with so-called clearance levels because the residual radioactivity in cleared scrap is not of an illicit nature and could only lead to negligible doses. The control procedures installed by plant operators and authorities are so effective that the probability for radioactivity being released incidentally in a serious amount is extremely low. (Clearance levels for metal scrap have been agreed upon internationally [3] and are also incorporated in the German regulatory framework [4].)

2. Origins for Radioactivity in Scrap
As already mentioned, there are two main pathways by which radioactivity can enter metal scrap:

- radiation sources, e.g. sources contained in technical or medical instruments that are not properly removed and handled when the device is scrapped,

- contamination in the form of scale or crud on the inner surfaces of pipes and large vessels or containers originating from the oil and gas industry.

A number of other origins is known, ranging from surface contamination due to Chernobyl fallout to radioactive material imported from Middle and Eastern Europe or the CIS.

The radionuclides and activities involved in each of these pathways vary considerably. One obvious but very important difference is the spatial distribution of the activity:

- In the case of radiation sources, the activity is localised in a very small area, the activities may be in the MBq or GBq range, but even very large sources with activities of TBq or even some 10 TBq have been found. The activity in such a source can usually not be dispersed which leaves only external irradiation as the relevant radiological pathway.
- In cases where the radioactivity is present as surface contamination, it is far less localised. However, the contamination may be released into the air by handling the material making inhalation as the second relevant radiological pathway possible. Although the total activity in the contamination may be high, the specific activity is at any rate much lower than in the case of radiation sources.

There is only a limited number of radionuclides that are usually found in scrap. In the case of radiation sources the most important nuclides are Co 60, Cs 137, Ra 226 or Sr 90. Where NORM contamination is present, the nuclide vector consists of varying amounts of the nu clides of the U and Th decay chains. Several other nuclides may be involved in special cases.

3. Incidents involving Radioactivity in Scrap

As already mentioned, the annual number of reported incidents has continuously increased since the early 1980's. It is therefore impossible to give a complete overview of all reports, even for a specific country. However, in order to give an idea of the nature of early and of recent reports some incidents have been compiled from [1] (table 1) and [2] (table 2).

Table 1 lists major incidents with large sources in the range of GBq up to 10 TBq. It is clear that in the "early days" of radioactivity detection in scrap, attention focussed on those more important incidents while many small sources or low level contamination may have slipped through undetected. As table 2 demonstrates, however, it is fortunately not those large events that account for the majority of detections. In many occasions only very small radiation sources or insignificant contamination are found. A more concise list of reports from Germany can be found in [2], very interesting case studies are available e.g. in [5], [6], [7], [8] or [9]. It should, however, not be ignored that a small number of significant accidents happened with large radioactive sources, e.g. in Estonia in 1994, where a military source with approximately 5 TBq Cs 137 was handled inadvertently by a scrap dealer, killing a man and injuring several otherpersons [10].

Table 1: **reported incidents (selection from the early 1980's) of radioactive material in steel or steel scrap (from [1])**

Date	Type of facility	Country	Radionuclide	Quantity [Bq]	Likely source
Feb. 1983	steel plant	USA	Co 60	10^{12},10^{13}	industrial radiography, medical therapy
Jan. 1984	steel plant, foundry, scrap yard	Mexico	Co 60	$1{,}5 \cdot 10^{13}$	medical therapy source in scrap
Aug. 1984	steel plant	Taiwan	Co 60	$\sim 10^{9}$	gauge in scrap
Oct 1984	steel plant	USA	Cs 137	$3 \cdot 10^{10}$	gauge melted when covered by molten steel
Jul 1985	steel plant	USA	NORM	unknown	scale in oil well casing

Table 2: **reported incidents (selection from 1995 and 1996) from Northrhine-Westphalia, Germany (from [21])**

Date	Type of facility	Radionuclide	Quantity [Bq]	Likely source
Mar 1995	steel plant	Ra 226 + decay products, Th 232 + decay product	250 Bq/g	pipe with 5 cm scale on inner surface
Oct 1995	steel plant	Ra 226 + decay products	18 MBq_{tot}	small radiation source
Nov 1995	steel plant steel	U_{nat}	3 - 70 Bq/g	5 sections of pipes
Jan 1996	plant steel plant	Cs137	15 Bq/cm^2 on floor of train car	contamination on floor of train car (from a previous incident)
Jul 1996	steel plant	Co 60, Na 22, Mn 54	10-100 µSv/h at surface of pipe	pipe in scrap from Russia
Jul 1996	steel plant	Ir 192	10 µSv/h at source container	radiation source in scrap from Russia

4. Detection Equipment at Foundries and Scrap Yards

Today, measurement facilities have been installed at the entrances to all German foundries and nearly all larger scrap yards. These measurement facilities allow the swift measurement of whole lorry or freight car loads. The lower limit of detection is for some devices as low as ~5 nSv/h (dose rate increase above background at the detector) which is achieved by very advanced hardware and software. This detection limit corresponds to the detection of a Co 60 point source of ca 7 MBq buried in the middle of the scrap load or of only ca 15 kBq if the source is close to the surface of the load.

Many commercial suppliers offer various equipment from hand-held detectors to complete stationary solutions. There seems to be a tendency towards systems that measure the total dose increase while only few systems use spectroscopy.

In addition to those measurements carried out by the industry on a voluntary basis, simplified dose rate measurements are performed by German customs officials at the eastern borders for scrap loads to be imported into Germany. These measurements serve to prevent radioactive scrap from entering the country and to send back the lorry immediately.

5. Analysis of the Radiological Consequences

When activity is detected in a load, several options exist, ranging from sending the scrap back to the sender to careful unloading and separating the load with the aim of localising and removing the contamination. The most common option in Germany is to send back the lorry or freight car to the sender immediately after detection of the radioactivity. At the same time the incident is reported to the competent authorities (in addition, details are usually also transmitted to other foundries or scrap yards in the vicinity in order to prevent the lorry driver from trying to get rid of his scrap elsewhere). In many cases the authorities decide to investigate the load prior to sending it back. The whole topic of the correct application of German and international transport regulations (dose rates, activity content etc.) and radiation protection legislation is in these cases very complicated and shall not be evaluated in this paper. The matter becomes still more complicated when the alarm is caused by NORM because in this case different parts of the legislation apply. Therefore, the focus of this paper lies on the radiological consequences.

It is clear that sending back a load in which radioactivity has been detected does not really solve the problem but shifts it from one place to another one. Finally, the scrap has to be un loaded and separated somewhere in order to localise the parts that caused the alarm. Further more it can be argued that any additional transport before the activity is removed by trained personnel increases the risk for the driver and eventually for other persons that might come into prolonged contact with the load.

The radiological consequences have been investigated in detail in [2]. Radiological scenarios have been devised on the basis of the actual procedures followed by the industry and the authorities for the following situations or workplaces: loading and transport of the scrap, unloading after radioactivity alarm, separating for identification of the source, removal and disposal of the source. In addition, the following situations have been investigated, assuming that the radioactivity went undetected and therefore was not removed: scrap yard (storage, handling, segmenting), foundry, product manufacturing, use of products and by-products, other use.

While all single results cannot be reported here, the main results can be summarised as follows: A realistic dose calculation shows that the probability for individual doses in the range of mSv or 10 mSv (per incident) is rather small, yet it is not zero. However, it can be expected that in the majority of cases individual doses will not exceed the range of a few µSv to several 10 µSv. The following persons are likely to receive the highest doses: the driver of a lorry (in the case of train or ship transport there is almost no risk for the driver or the personnel on board of the ship) and the persons that unload the scrap. In cases where radiation sources would pass without detection the personnel at scrap yards or foundries, who come into close contact or even separate the scrap manually, can likewise receive high doses. This underlines the radiological relevance of the problem of hidden radioactivity in scrap.

This short discussion also reveals that a hidden radiation source is much more dangerous than a broadly distributed contamination on the surfaces of the scrap, even if inhalation of resus pended contamination is taken into account. Large radiation sources that remain undetected and that are handled without knowledge or carelessly have even the potential to kill people [10]. If a large radiation source reaches a foundry and is melted its activity is either homoge neously distributed in the product metal (Co 60, Ir 192 and other radionuclides) or goes to the slag or filters (Cs 137). Nuclides from NORM are mainly transferred to the slag in the melting process. In any case the specific activity is drastically reduced which also reduces the overall radiological hazard, but such an incident can still lead to large scale contamination in products irradiating people (see e.g. [6]) or to large scale contamination in a plant (see e.g. [7], [8]). The costs for the removal of the activity can be extremely high and can well cause financial disaster for a company.

6. Recommendations for Safe and Cost Effective Procedure in case of Radioactivity Alarm

The continuous increase in the number and sensitivity of measuring devices also leads to an increase in the probability that traces of NORM are detected in scrap loads. Because each detection of radioactivity means unnecessary costs and great efforts to localise and remove the contamination, it is important to avoid these incidents as reliably as possible. Several approaches already exist in Germany. Guidance on how to avoid radioactivity in scrap and how to proceed after detection is provided e.g. in [11]. More specific guidance for the German oil and gas industry is given in [12] where procedures are recommended how to remove the activity bearing scale and residues from pipes and vessels used for oil and gas production and storage. These procedures aim at removing radioactivity already at the source before it can enter the material cycle. The analysis performed in [2] suggests a well defined procedure to be followed which is based on measurements and interaction between the responsible persons in the plant (scrap yard, foundry etc.) and the competent authorities. It aims at reducing unnecessary transports and costs by careful unloading and separating of the scrap after the activity detection. In following this procedure, all available information have to be taken into account like origin of the scrap (scrapped devices that may contain radiation sources; contamination by NORM or other substances), visual appearance (scale in pipes), dose rate measurements of the entrance detector and additional measurements with hand-held devices, spatial distribution of the dose rate etc. The next steps should be determined by the results of the dose rate measurements:

- If this is very low (e.g. around 0,1 µSv/h) the load could be carefully unloaded and separated by the personnel, the authority should be informed. The material could also be smelted directly because the chance that a large source is hidden in the scrap is very low. (Of course, the material could also be sent back).

- If the dose rate is between 0,1 and 5 µSv/h (limit value of the transport regulations) the authorities should be contacted and any further procedure should be co-ordinated and controlled by the authorities, but unloading and separating could be done by the personnel of the plant. The material could also be further processed or sent back.

- If the dose rate is above 5 µSv/h the lorry or freight car should be secured, and all further steps should be carried out by the authorities.

This procedure which relies on the action levels 0,1 µSv/h and 5 µSv/h would reduce unnecessary and cost intensive work of the authorities yet ensuring a high level of safety for the involved personnel and people of the general public. Until now, this procedure only remains a proposal, but it would be interesting to gather experience from its implementation at a selected foundry or scrap yard over a limited period of time in order to decide whether it could be implemented in Germany on a broader scale.

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