Operational aspects of decommissioning of installations containing mineral wool

E.I.M. Meijne, G. Gul and M.L.J. Kok, NRG, Radiation & Environment, The Netherlands

Between 1948 and 1960 tin slag, a residue of tin smelting, was used on a large scale for the production of mineral wool. In The Netherlands, this so-called slag wool, was applied as insulation material in a wide range of equipment and installations, for example doors, bakery ovens, steam generators and a coal-fired power plant. Many of these installations or plants are now at the end of their life span and are being dismantled.

At the time of application the radiological character of the slag wool was not recognised. The awareness that slag wool contains enhanced concentrations natural radionuclides came when scrap triggered portal radiation monitors installed at scrap yards due to the presence of adherent slag wool. Gammaspectrometric analysis of slag wool samples showed the presence of radionuclides from the U-238 and the Th-232 chain with activity concentrations at about 4 Bq/g and 11 Bq/g respectively.

Under current Dutch law this material falls under authorisation and is classified as radioactive material. The presence of slag wool inside installations being dismantled involves both exposures to external radiation as well as internal radiation due to inhalation of slag wool particles. Due to the inert matrix of the slag wool the lung class for all radionuclides is S(low). External dose rates on the surface of equipment insulated with slag wool in general do not exceed 1 μSv/hr. The radiation dose due to internal exposure strongly depends on whether the radiological character of the slag wool was recognised before dismantling started and ranges for 1 to 1.5 mSv per gram inhaled dust. Some installations were already partly demolished before the slag wool was identified and radiation protection measures started.

Besides radiation protection measures during decommissioning, disposal of the remaining waste is an important issue. Under current Dutch legislation the slag wool has to be transferred to the Central Organisation for Radioactive waste (COVRA) at high costs (approximately 20 Euro/kg) if the slag wool has to be considered "radioactive waste". Options for re-use of this material are therefore under investigation and will possibly influence the way the material is pre-treated to minimise exposure of workers during reuse of this material. This paper describes the experience in The Netherlands with decommissioning of installations containing slag wool.

1 INTRODUCTION

Since the installation of portal monitors at scrap yards a large number of incidents has been reported in which portal monitors detected the presence of “radioactive” insulation wool, usually referred to as slag wool. The slag wool incidents cover a large variety of components including steam generators for green house heating, ovens, piping, doors insulated with mineral wool, the roof of a tile factory and a huge power plant.

On behalf of the Dutch Government KEMA and NRG carried out a survey to retrace the origin and the amount of slag wool that could be present in various installations. It appeared that the radionuclide concentrations and the ratio between radionuclides of the U-238 and Th-232 decay series matched well with slag from a former Dutch tin smelter stored at COVRA. Further inquiries revealed that producers of mineral insulation wool indeed have used slag from the Dutch tin smelter during a limited period of time, probably between 1946 and 1960. The bulk of mineral wool produced over those years was made from other raw materials, slag from steel production and basalt with much lower concentrations of natural radionuclides. The KEMA survey estimated the total amount of mineral wool produced with slag from tin smelting between 800 and 2200 tons [1].

2 CHARACTERISTICS OF SLAG WOOL

Gammaspectrometric analyses show that slag wool is characterised by higher concentrations Th-232 than U-238. The average ratio Th-232/U-238 is about 3 and varies from 4.2 to 1.8 (see Table 1). Ra-226 and its short-lived daughters are in equilibrium with U-238. Pb-210 (and consequently also Po-210) are slightly depleted. The ratio Pb-210/ Ra-226 is about 0.8. From this ratio an average age for slag wool of approximately 50 years can be calculated if it is assumed that all Pb-210 was volatilised at the time of slag or slag wool production. This coincides with the production period of tin slag.

Figuur 1. In-growth of Pb-210 from Ra-226

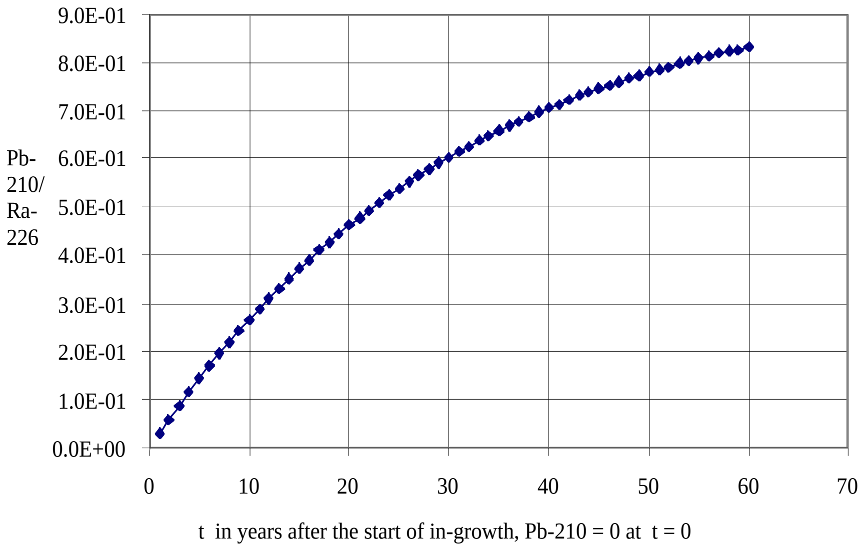

Table 1. Activity concentrations of natural radionuclides in forty slag wool samples from Dutch installations.

	U-238 - Ra-226 Bq/g	Pb-210 Bq/g	Th-232nat Bq/g	Total Bq/g	Sum BS	Th-232 / U-238	Pb-210 / Ra-226
Maximum	6.2	3.8	16	220	22.2	4.2	1.0
Minimum	2.6	1.7	5.9	40	8.5	1.8	0.4
Mean	4.0	2.9	11.2	162.7	15.2	2.8	0.8
Standard deviation	0.8	0.5	2.1	27.7		0.5	0.1

Chemical analyses showed that Si (SiO_2), Ca (CaO), Fe (Fe_2O_3), Ti (TiO_2) and Mg (MgO) are the most abundant elements in slag wool.

At the time of application of slag wool as insulation material no regulations with regard to NORM existed. The activity concentrations of the radionuclides in the slag wool exceed however the limits above which possession and handling of the material requires an authorisation under the current Nuclear Energy Act (sum BS is higher than 10) (see Table 1). Wastes from the non-nuclear industry, which exceed the activity concentration limits, may only be disposed of by transfer to the only organisation authorised to receive radioactive waste, COVRA.

No actions have been undertaken until now by the Government to identify and notify potential owners of installations containing slag wool as insulation material. In many cases the owners of these installations therefore only become aware that radioactive material was present once decommissioning was started and disposed waste triggered a portal monitor at a scrap yard. To illustrate the radiological and economical consequence of the presence of slag wool the decommissioning of a fossil-fuelled power plant is described below.

3 DECOMMISSIONING OF A FOSSIL-FUELLED POWER PLANT

In 1998 the dismantling of a former fossil-fuelled power plant in Rotterdam was started (picture 1). At the end of 1999 when dismantling of the oldest two kettles (number 1 and 2) was started, a 20-foot container with scrap from the plant was sent to a scrap dealer were the container triggered the alarm of the portal monitors. Consequently, the Dutch Inspectorate was notified and the dismantling of the power plant was stopped. Investigation of the 20-foot container carried out under supervision of a radiation protection officer showed that the insulation wool that was attached to the metal parts from the installation caused the enhanced dose rate measured by the portal monitor. Gammaspectrometric analyses of the material showed that natural radionuclides were present at concentration levels that required a licence for possessing, handling and processing of the material. In addition the material had to be regarded as radioactive waste if no re-use option was foreseen. Because neither the buyer nor the dismantler of the power plant was in the possession of a licence according to the nuclear energy act further dismantling of the power plant was continued under the licence of NRG and under supervision of radiation protection officers from NRG.

Because the presence of radioactive material had not been considered when decommissioning was started the demolishing of the slag wool containing kettle 1 and 2 had been carried out in an uncontrolled manner. As a consequence slag wool was spread over a large area and large parts of the installation containing slag wool were opened (picture 2). Before the dismantling of the power plant could be continued, now under radiological controlled conditions, the present situation had to be rehabilitated by collecting the slag wool spread onto floors and covering the slag wool containing parts of the installation that were only partly dismantled.

A work plan specifying how the work activities would be carried out had to be submitted to the Inspectorate. The main aim of the work plan was prevention of spreading of slag wool in the building and to the environment, prevention of exposure of workers and removal of the slag wool. The work activities were performed in a supervised area by qualified asbestos removers under supervision of a radiation protection officer. Personal protection equipment included Tyvec coveralls, gloves, safety boots and breathing protection (Power packs with P-3 filter, picture 5). A vacuum cleaner type HDZ 750 with absolute filter was used to remove smaller slag wool parts and a shower unit was installed at the end of the supervised area. Large openings in the building were closed by means of containers (picture 3). Spreading of slag wool in the building was prevented by constructing compartments by means of scaffoldings and plastic foil (picture 4). All slag wool was put in double plastic bags and stored in containers. Building rubble and soil containing trace amounts of slag wool were collected in big bags and sampled. On the basis of gammaspectrometric analyses these could be released as non-radioactive waste. It took a few months to collect all slag wool spread in the installation by the uncontrolled demolishing of the building.

The decommissioning of the power plant could be continued in March 2000. With a surface contamination monitor measurements were performed in the entire installation. All parts containing slag wool were marked. A plastic containment was build around all remaining slag wool containing parts of the installation to allow for controlled decommissioning and prevent the spreading of radioactive material.

4 RADIOLOGICAL ASPECTS OF SLAG WOOL

Exposure of workers during dismantling of slag wool containing installations depends for a large part on the precaution measures taken during decommissioning and thus on the fact if radioactivity was recognised before the start of the dismantling. The presence of slag wool leads to external exposure as well as internal exposure due to the inhalation of slag wool particles. The radiation dose due to internal exposure depends on the activity concentration, the chemical characteristics of the material inhaled and the precaution measures taken. Slag wool has an inert glass matrix with lung class slow (S) and a very low radon emanation coefficient. The dose coefficients for radionuclides inhaled with slag wool (see table 2) are therefore higher than those given in the European Basic Safety Standards (BSS).

Table 2. Dose coefficients for workers handling slag wool and those listed in the BSS

Nuclide	Lung class	DC 5 µm AMAD, Sv/Bq	Lung class BSS	DC 5 µm AMAD, Sv/Bq in BSS	Ratio DC Slag wool/BSS
U-238++	S	$2.6\ 10^{-5}$			
Ra-226+	S	$4.0\ 10^{-5}$	M	$2.2\ 10^{-6}$	18
Pb-210+	S	$4.9\ 10^{-6}$	F	$1.2\ 10^{-6}$	4.1
Po-210	S	$3.2\ 10^{-6}$	M	$2.2\ 10^{-6}$	1.5
Th-232	S	$1.2\ 10^{-5}$			
Ra-228+	S	$1.3\ 10^{-5}$	M	$1.8\ 10^{-6}$	7.2
Th-228+	S	$3.5\ 10^{-5}$			

++ U-238 including short-lived daughters, U-234, Th-230 and U-235.
\+ Mother radionuclide including short-lived daughters.

The estimated dose due to inhalation of 1 gram slag wool varies between 1 mSv to 1.4 mSv dependent on the activity concentration of the slag wool (Table 3). The amount of slag wool inhaled is however strongly dependent on the work conditions during dismantling. If the presence of slag wool is not recognised at the start of the decommissioning and dismantling is carried out without respiratory protective equipment the dose due to internal exposure may be above 1 mSv for large installations (Table 5). The use of respiratory protective equipment will decrease the dose due to internal exposure significantly. Even when Assigned Protection Factors are applied in stead of Nominal Protection Factor the dose due to internal exposure is still low. The estimated dose due to internal exposure during dismantling of the slag wool containing power plant is estimated of 28 µSv based on 500 hours work time and the use of powerpacks as RPE.

Table 3. Dose coefficients (DC) for inhalation of nuclides from slag wool based on 5 µm AMAD and Type Slow.

Nuclide	DC in Sv/Bq	Average conc. Bq/g	DC in Sv/g inhalation	High conc. Bq/g	DC in Sv/g inhalation
U-238 – Ra-226	$6.6\ 10^{-5}$	4	$2.6\ 10^{-4}$	6	$4.0\ 10^{-4}$
Pb-210 – Po-210	$8.1\ 10^{-6}$	3	$2.4\ 10^{-5}$	4	$3.2\ 10^{-5}$
Th-232 – Po-212	$6.0\ 10^{-5}$	11	$6.6\ 10^{-4}$	16	$9.6\ 10^{-4}$
Total			**$9.5\ 10^{-4}$**		**$1.4\ 10^{-3}$**

Table 4. Scenario conditions and parameters for external and internal exposure to slag wool during dismantling of installations.

Scenario	Radioactivity recognised / RPE[1)]	Size of installation	Exposure hrs/a	Slag wool dust conc. mg/m^3	Breathing rate m^3/h
A	No	Small	20	1	1.2
B	Yes	Large	500	2	1.2
C	No	Large	500	2	1.2

[1)]RPE = Respiratory Protective Equipment

External dose rates on the surface of slag wool insulated equipment in general do not exceed 1 µSv/h at an average dose rate. At working distance (1 m) dose rates have been measured up to 0.8 µSv/h near large pieces of equipment. A mean dose rate at working distance of 0.3 µSv/h seems however a good estimate for dose assessments when larger installations are dismantled. If the presence of slag wool is recognised at the start of the decommissioning the total dose for workers due to the decommissioning will be below 1 mSv. If demolition work is carried out for prolonged periods without adequate radiation protection equipment dose above 1 mSv may be received. High doses are however unlikely.

Table 5 Estimated radiation exposures to slag wool at dismantling of installations.

Scenario	RPE / PF	External exposure mSv/a	Internal exposure mSv/a	Tota
A	No	0.006	0.023	
B1	FFP3 – NPF 40	0.15	0.028	
	FFP3 – APF 20	0.15	0.057	
	FFM PA NP – NPF 2000	0.15	0.001	
	FFM PA NP – APF 40	0.15	0.028	
C	no	0.15	1.138	

RPE = respiratory protective equipment, NPF = Nominal protection factor, APF = assigned protection factor, FFM PA NP = full-face mask power assisted negative pressure.

NPF represent the performance of Respiratory Protection Equipment (RPE) when tested against a European standard, simulated in laboratory conditions. NPF were used previously to define the protection supplied by respiratory protection equipment. However, extensive workplace protection factor studies have shown that actual protection levels achieved in the workplace differ significantly from those calculated in the lab, even when RPE is correctly worn and used. These studies have lead to the introduction of Assigned Protection Factors. In most cases APFs are considerably lower. These are the levels of protection which can be realistically achieved in the workplace if wearers are correctly trained and supervised and if the equipment is correctly fitting and properly functioning. For example a power assisted full-face mask with negative pressure and with P3 filter with a NPF of 2000 has an APF of only 40 (BS 4275).

5 VOLUME REDUCTION OF WASTE

After dismantling of the power plant 36 tonnes of slag wool remained stored in hundreds of plastic bags (picture 6). Because the activity concentration was above the concentration level for radioactive material requiring authorisation, the material has to be stored at COVRA if considered as radioactive waste. Solid waste has to be packed in 100 litre metal COVRA drums. The maximum weight of the content in a drum is 60 kilograms. To reduce the volume of the waste, the slag wool was compressed with a press (picture 7) and stored in plastic bags (sausages) each weighing approximately 30 kilograms (picture 8). Compression reduced the volume and thus the size of the storage facility and facilitated the handling of the waste. Moreover in case no other option would become available two plastic bags could be placed in one COVRA drum to allow optimal filling of the drums to reduce the costs of waste disposal as much as possible. Even when optimal filling of COVRA drum could be obtained the costs of transfer of the slag wool into COVRA drum and transfer to COVRA are estimated at about 650,000 EURO, more than 100 times the cost of disposal to a normal landfill.

In collaboration with the Ministry of VROM options for re-use of the slag wool have been investigated. A possible option that will be investigated is the use of slag wool as replacement for gravel at a phosphorus production plant. To be able to feed the slag wool into the ovens of Thermphos the slag wool had to be repacked in 15 litre drums. During repackaging of the slag wool in 15 litre drums it appeared that compressing of the slag wool had led to pulverisation of the material (figure 9) making it extremely difficult to handle without the generation of a lot of dust (figure 10). Storage of slag wool in big bags is therefore preferred option above compression until a final re-use option / disposal options for slag wool has been agreed upon.

6 CONCLUSION

Slag wool can be encountered as insulation material in old installations. The decommissioning of the installation will not lead to doses far above 1 mSv per year, even if the radioactive character of the slag wool is not recognised at the start of the dismantling. The main problems of slag wool in The Netherlands are the very high costs of disposal of the material to COVRA. The demolishing of one bakery oven for example resulted in disposal costs of approximately 114.000 Euro due to the fact that the radioactive character of the slag wool was only identified after the start of demolishing. At that time the slag wool was inseparable mixed with other debris. Re-use options for this material are under investigation. The radiological character of this material however makes re-use options difficult to accomplish even though doses to workers or members of public due to the proposed re-use options are negligible.

7 REFERENCES

1. S. Th. M. Stokman-Godschalk, Confidential report 50160743-KPS/MEC 01-6118 to the Ministry of Housing, Spacial Planning and the Environment, Arnhem, 17 July 2001.
2. C.W.M. Timmermans en A.W. van Weers, *Werkzaamheden met blootstelling aan natuurlijke stralingsbronnen*, actualisatie van de inventarisatie van 1999, SZW publication, No 200, 2001.
3. BS4275 Guide. British Standard BS4275 - respiratory protective equipment programme.

Picture 1 : Fossil fuelled powerplant

Picture 2 : slagwool visible after uncontrolled dismantling

Picture 3 : Example of remedial actions taken to prevent spreading of slag wool to the environment.

Picture 4 : Example of remedial actions taken to prevent spreading of slag wool in the building.

Picture 5 : Collection of slag wool

Picture 6 : Slag wool remaining after Decommissioning.

Picture 7 : Compression of slag wool

Picture 8 : Compressed slag wool

Picture 9 : Slag wool after compression

Picture 10 : Filling of 15 litre test drums