Occupational exposure during site remediation at WISMUT

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1 Introduction

From 1946 to 1990 the Soviet-German WISMUT Company mined and milled 231,000 tons of Uranium and became with it the world's third largest uranium producer at that time. Production was accompanied by an amount of 800 Million t of waste, and resulted in seriously affected and devastated areas in a densely populated region of about 10,000 km_. In 1990 after the German re-unification the uranium production was ceased and the German government was faced with one of its largest ecological and economic challenges because WISMUT turned at once from the production to the decommissioning phase without any preparation or preplanning. Since 1991 the national corporation WISMUT GmbH has been charged with the decommissioning of the mines, mills and other facilities and with the rehabilitation of the sites.

Since decommissioning and site remediation are carried out at places with enhanced dose rates and high concentrations of airborne radioactivity (long-lived alpha particles, radon progenies), a large part of the employees is classified as occupationally exposed radiation workers. The paper presents the results of dose estimates and individual dosimetry as well as the measures taken by WISMUT to optimise the occupational exposure. The need for implementing appropriate ALARA methods in the field of occupational exposure is last but not least caused by the fact that for a number of employees the integral exposure over the total working life time has exceeded already the 400 mSv figure.

2 The WISMUT rehabilitation project

The radiological situation immediately after the termination of uranium production in 1990 is best characterised by the following figures relating to environmental impacts and liabilities.

- 37 km_ „WISMUT-covered“ region; in federal states having a high population density: Saxony 247 inhabitants/km_, Thuringia 154 inhabitants/km_
- 311 Mio m_ waste rock piles, 48 piles (20 at the Schlema site), typical specific activities: 0.2 ...2 Bq/g (Ra-226); inventory: 20'000 t Uranium
- 30.6 Mio m_/a seepage water; 27 t/a Uranium controlled release into surface waters
- Radioactive emission via ventilation shafts (Schlema site); 900 TBq Rn-222, 130 MBq long-lived alpha emitters
- 5.7 km_ tailings pond surface, 178 Mio m_ sludge (Seelingstädt and Crossen site); specific activities: 1 .. 10Bq/g Ra-226; Inventory: 1800 TBq (Ra-226), 16'000 t Uranium
- 1,6 km_ open pit; 84 Mio m_ open volume (Ronneburg site)
- 5 mines (in Schlema, Königstein, Ronneburg, Gittersee); 1.53 Mio m_, 1470 km length;
- 2 processing plants awaiting decommissioning, dismantling and demolition
- large amounts of radioactively contaminated waste (for instance 260‘000 tons of metallic scrap)

Major remediation activities include:

- Backfilling of the Lichtenberg open pit (Ronneburg site) using materials excavated from nearby mine dumps followed by the placement of a cover.
- Grading and covering of mine waste piles at the Aue site.
- Dry in situ rehabilitation of tailings management facilities involving removal of supernatant and pore waters, geotechnical stabilisation and covering.
- Demolition of structures and disposal of contaminated materials.
- Controlled flooding of underground mines and treatment of contaminated mine waters.

The German federal government committed a total of € 6,2 billion to the remediation of the left behind liabilities. Given the well advanced state of the remedial operations, about 65 % of the funds were spent by the end of 2002. To date, WISMUT still employs 2,500 persons. Together with contractors, WISMUT will have completed the bulk of remedial actions by the year 2015. Some tasks such as water treatment and long-term monitoring will have to be pursued beyond that time frame.

3 Regulation of the occupational exposure

§ 55 of the German Radiation Protection Ordinance [StrSchV-01] stipulates a limit of 20 mSv per calendar year on effective dose. There is also a limit of 400 mSv (working life dose set by § 56 of the Radiation Protection Ordinance) on the total of effective dose for occupationally exposed persons. Further occupational exposure is made subject to medical check, with the understanding that the annual dose must not exceed 10 mSv. These limits do also apply to WISMUT workers, irrespective of the fact that the old Nuclear Safety and Radiological Protection Ordinance [VOAS-84] of the former GDR is still in effect for the rehabilitation of the legacies of uranium mining operations in East Germany, (cf. Radiation Protection Ordinance, § 118). Classification of remediation workers as occupationally exposed category A workers or category B workers is based on anticipated occupational effective doses in excess of 6 mSv/a (category A) or in excess of 1 mSv/a (category B), respectively.

By analogy to the above, WISMUT areas where remediation workers may be exposed to effective doses exceeding 1 mSv/a are classified as supervised areas. Such areas include any mine waste pile as well as contaminated plant areas and tailings management facilities. Controlled areas are those where persons may be exposed to radiation doses in excess of 6 mSv/a. In the case of WISMUT, this applies to any still accessible underground mine, in particular at the Königstein and Aue sites. There are no exclusion areas at WISMUT where gamma dose rates may exceed 3 mSv/h, as defined by § 36 of the Radiation Protection Ordinance.

With regard to the underground areas, internal company secondary limits were derived on Radon/Radon progeny (potential alpha energy concentration C_{pot}), on gamma dose rate as well as on the concentration of dust-borne long-lived alpha emitters. Relevant dust-borne long-lived alpha emitters include the radionuclides U-238, U-234, Th-230, Ra-226 and Po-210 of the U-238 decay series, as well as the nuclide U-235. Based on a total of 2,000 working hours underground, the following secondary limits may be derived by approximation from the dose limit of 20 mSv/a:

- potential alpha energy concentration of Rn decay products C_{pot} :	40 MeV/cm_
- dust-borne long-lived alpha emitters C-llα :	830 mBq/m_
- external Gamma dose rate H*(10) :	10 µSv/h

As all three exposure pathways

- inhalation of Radon/Rn decay products;
- inhalation of dust-borne long-lived alpha emitters;
- external radiation

have to be considered for underground remedial works, a summation formula will have to be used. Occupational exposure levels of C_{pot}, H*(10) and C-llα are required to be:

$$\frac{C_{pot}}{40\,MeV/cm^{-3}} + \frac{C_{ll\alpha}}{830\ mBq/m^3} + \frac{H^*(10)}{10\,\mu Sv/h} < 1$$

Therefore, workers employed in remedial operations underground are category A workers (514 workers in 2002). By analogy, persons working above ground in monitored areas and employed in mine cleanup and remedial operations are category B workers (1073 workers in 2002).

4 Typical working place conditions and resulting effective doses

Table 1 below provides a picture of typical workplace concentrations and gamma dose rates and of related effective doses.

Tab. 1: Typical concentration and dose levels at WISMUT workplaces and related effective doses

Type of work	Radiological parameter	Typical workplace level	Effective Dose [mSv/a]
Above ground works (2000 h) Mine waste pile remediation (mean specific activity 1 Bq/g Ra-226; 0.5 Bq/g U-238)	Gamma dose rate H*(10) Rn concentration (F=0.2)* C-llα (1 mg/m_ dust)**	500 nSv/h 100 Bq/m_ 20 mBq/m_; nuclides in radioactive equilibrium	0.60 0.31 0.47 Total: 1.38
Tailings pond remediation (4 Bq Ra-226; 0.2 Bq/g U-238)	Gamma dose rate H*(10) Rn concentration (F=0.2) C-llα (0.4 mg/m_ dust)	2000 nSv/h 100 Bq/m_ 20 mBq/m_; no radioactive equilibrium	2.40 0.31 0.43 Total: 3.15
Underground works (1720 h)	Gamma dose rate H*(10) C_{pot} C-llα (1 mg/m_ dust)	300 nSv/h 10 MeV/cm_ 20 mBq/m_; nuclides in radioactive equilibrium	0.31 3.86 0.40 Total: 4.57

* F: Equilibrium factor between short-lived Rn progenies and Radon

** Cf. example 1 further down

For the benefit of a better illustration of the above levels, examples 1 and 2 provide more ample information on mine waste pile remediation and underground remediation works.

Example 1 - Outdoor remediation work (2000 hours)

Contouring of a dump; waste rock material of 1 Bq/g Ra-226; radioactive equilibrium

- Ambient dose rate H*(10): 500 nSv/h
  Gamma dose rate H*(10), working time t_w and effective dose due to external Gamma radiation Eγ are related according to: $E\gamma = 0{,}6 \cdot H^*(10) \cdot t_w$
- Rn concentration: 100 Bq/m_; F = 0,2
  Conversion of Radon concentration into inhalation dose is made on the basis of the dose convention under [ICRP 65].
- Dust concentration C-llα: 1 mg/m_
  As specific activity in fine-grained dust is about four times higher than the average specific activity of waste rock material, the atmospheric concentration of each of the five long-lived alpha emitters of the U-238 chain in supposed radioactive equilibrium is 4 mBq/m_, the level for U-234 is 0.045 x 4 mBq/m_: On the whole, the level of C-llα concentration is about 20 mBq/m_.

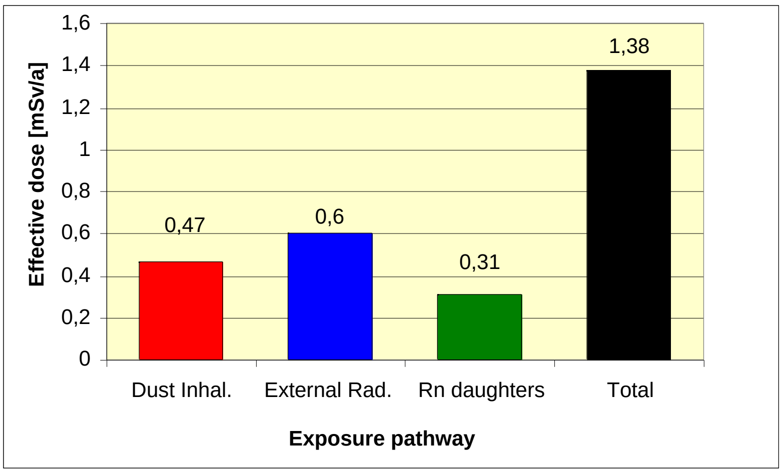

Fig. 1: Contribution to effective dose from various exposure pathways during typical works performed for waste rock pile remediation

Example 2 - Underground remediation work (Königstein mine, 2001)

For maximum exposure:

- Working time: 1720 hours
- Potential alpha energy concentration of the short lived alpha progenies C_{pot}= 19,3 MeV/cm_
- Dust-borne long-lived alpha emitter concentration llα = 96 mBq/m_
- Ambient dose rate: 440 nSv/h

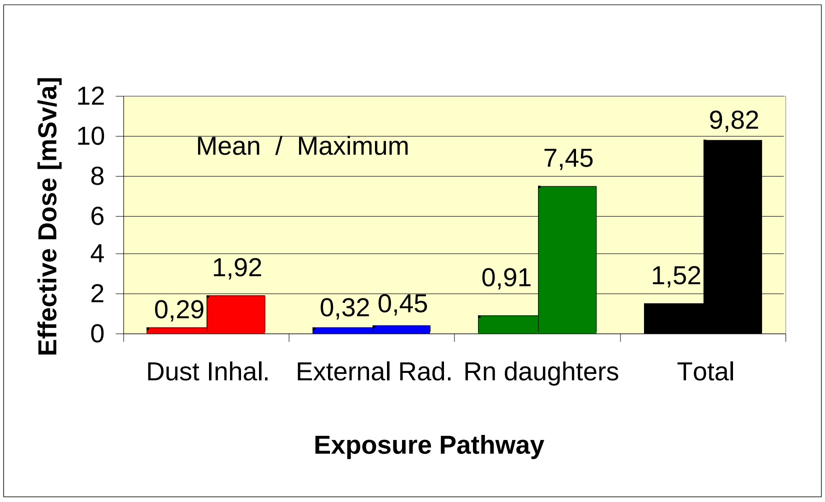

Fig. 2: Contribution to effective dose from various exposure pathways during execution of typical underground remediation work (left: averages of radiological parameters; right: peak levels at Königstein mine in 2001).

5 Personal radiological monitoring results

At WISMUT, any occupationally exposed worker is monitored. To this end, category A workers carry personal dosemeters of the "CEA-SPT" type (manufactured by ALGADE, France). These dosemeters allow to determine the radiological parameters: individual Gamma dose $H_p(10)$ [by means of TL detector], Radon/Radon progeny concentration [by means of track etch detector] and llα concentration [integrated mini-pump collects dust on a filter; subsequent alpha counting].

Reference persons employed in above surface remediation work are also equipped with CEA-SPT dosemeters. These reference persons represent groups of workers doing similar jobs. In addition to this, results of area monitoring at workplaces are analysed in order to determine radiation exposure to groups of workers. Table 2 provides a picture of individual doses established in 2002 at. Table 3 shows the effective dose in 2002 to occupationally exposed persons having received a working life dose in excess of 400 mSv.

Tab. 2: Individual doses to workers employed in the remediation of mining-related liabilities at WISMUT (year 2002).

Site	Number of category A workers	Effective Dose Category A [mSv]		Number of category B workers	Effective Dose Category B [mSv]	
			max			max
Ronneburg/Seelingstädt	0	-	-	637	0.3	2.2
Crossen	0	-	-	96	0.3	1.0
Aue	243	0.8	4.7	186	0.3	1.2
Königstein	271	1.0	4.9	154	0.4	1.3
WISMUT total	514	0.9	4.9	1073	0.3	2.2

Tab. 3: Individual doses in 2002 to workers at WISMUT having received a working life dose > 400 mSv.

Site	Number of category A workers	Effective Dose Category A [mSv]		Number of category B workers	Effective Dose Category B [mSv]	
			max			max
Ronneburg/Seelingstädt	0	-	-	127	0.2	0.5
Crossen	0	-	-	2	0.3	0.3
Aue	65	0.8	4.6	26	0.3	0.4
Königstein	0	-	-	4	0.4	0.6
WISMUT total	65	0.8	4.6	159	0.2	0.6

Figure 3 illustrates the development of radiation exposure at WISMUT.

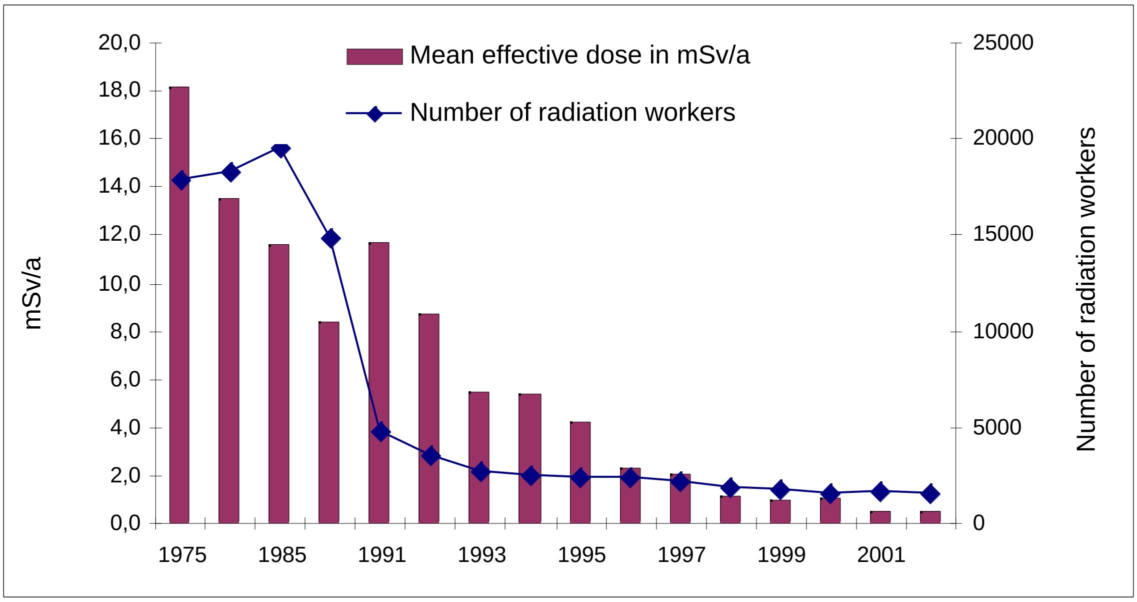

Fig.3: Mean effective doses of radiation exposed WISMUT from 1975 to 2002. Note: At the end of 1990 the Uranium production was terminated. From this time on, the company has dealt with rehabilitation.

6 Evaluation and Conclusions

Comparison of average effective doses to both category A workers and category B workers reveals that radiation exposure in 2002 (like in previous years) was well below regulatory limits. The same is true of peak levels. The highest dose levels were recorded without exception during underground works in preparing mine flooding at the Königstein and Aue sites.

In 2002, the effective dose to 88 % of occupationally exposed persons was below 1 mSv, 12 % of the affected workers were exposed to dose levels between 1 and 6 mSv/a. While the maximum effective dose was still close to 10 mSv in 2001 (cf. Fig. 2), there was no peak recorded greater than 6 mSv in 2002.

The findings of personal radiation monitoring are also below effective doses estimated from workplace concentrations and dose rates (cf. Table 2 vs. Table 1). This is due to workers moving between workplaces and to varying job content which makes that, as a rule, workers to not stay for a working time of 2000 h or 1720 h, respectively, at the locations to which concentration and dose levels in Table 1 apply.

Low individual doses are first and foremost due to a well established system of radiation protection practice within WISMUT. Relatively low exposure to radiation makes specific work regimes unnecessary. There a merely a few workplaces underground showing extreme concentration levels were access is subject to a time limit.

Radiation exposure to workers above ground can be kept low by applying some simple precautions, such as:

- wearing specific work clothes; hygiene measures (showers; boots scrubbing, etc.);
- wearing of dust masks during demolition work;
- moisturising of building debris, watering of haulage roads and transported goods (waste rock) during dry spells.

Underground radiation protection is assured by a vast ventilation system operated at the Königstein and Aue mines. When mine sections are abandoned, individual workplaces may be cut off from the ventilation system. In such case, secondary aeration tubes and fans are used to ensure ventilation locally (auxiliary ventilation). Respirators are required underground in case of concentration levels above 40 MeV/cm_ for C_{pot} and during dust-generating works.

Admission of workers having a working life dose > 400 mSv to controlled or supervised areas is subject to a personal statement declaring their consent. They are informed regularly about occupational risks involved and have a medical check once a year. Employers are obliged to have these workers only jobs done where effective doses < 10 mSv/a are definitely respected. At WISMUT, this is clearly laid down by internal company regulations.

In summary, occupational radiation protection at WISMUT may be considered as having been optimised according to the ALARA principle.

References

[ICRP-65] Protection against Radon-222 at Home and at Work, ICRP Publication 65, 1994.

[StrSch-01] Verordnung über den Schutz vor Schäden durch ionisierende Strahlen (Strahlenschutzverordnung - StrlSchV), vom 20. Juli 2001; BGBl. I S. 1714.

[VOAS-84] Verordnung über die Gewährleistung von Atomsicherheit und Strahlenschutz (VOAS), GBl. I, Nr. 30 der DDR vom 21. November 1984.