East German Uranium Miners (Wismut)—Exposure Conditions and Health Consequences

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Abstract. Underground uranium mining was performed in East Germany after World War II on a large scale. East Germany was the main supplier of uranium for the Soviet Union. This review gives a historical summary and describes the broad spectrum of exposure to potential health hazards and the health consequences. Working conditions were very poor during the postwar years from approximately 1946-1955: there was drilling with air floating and a lack of forced ventilation. Dust levels were very high and there was a significant inhalative incorporation of α-radiating substances, mostly from short-lived radon progeny. However, long-lived α-radiating substances such as uranium-238 contributed considerably to the radiation dose. There was also exposure to toxic chemicals, such as arsenic (in some mines) or crystalline silica, and a variety of other health hazards. From approximately 1956-1970, mining conditions improved: there was drilling with the addition of water and forced ventilation of the mines. As of approximately 1970, compliance with rules of industrial hygiene and international standards of radiation protection was evident. In 1990, uranium production was generally stopped. To date, more than 5,000 cases of bronchial carcinoma are accepted as compensable occupational diseases and more are expected. The extensive data from Wismut uranium mining could improve our understanding of a complex exposure situation resulting in a variety of health impairments other than lung cancer.

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Introduction

After World War II, in the part of Germany which was occupied by the Soviet Union and later became the German Democratic Republic (GDR), uranium mining was performed on a large scale. Working conditions were very poor during the first postwar years. There was significant chronic exposure to ionizing radiation and other health hazards. The following review gives a historical summary and describes the broad spectrum of exposure to potentially harmful agents and the subsequent health impairments and diseases.

History of Mining in the Ore Mountains

For centuries the Ore Mountains in Central Europe, which divide Saxony and Bohemia, have been one of the most important mining regions in the world. Human settlement of this area started in the 12th century. In 1168, the discovery of silver initiated systematic silver mining ("Berggeschrey") [1]. Later, this led to several foundations of towns in that region, among them Schneeberg, known in Occupational Medicine for Schneeberg lung disease. In the 15th and 16th centuries, mining for silver and iron ore was at its height. The production of silver became the economic basis of power for the princes of Saxony. Still, in 1680-1730, the annual production was approximately 4.5 tons in the Schneeberg area alone [2]. In later years, silver mining lost its importance.

Since the end of the 15th century, other elements were mined as well, such as nickel, cobalt and wismut. There was also mining of uranium oxides since the end of the 19th century when it was used as a pigment for the coloring of porcelain and as an additive for the coloring of melted glass ("Annagelb") [2]. For centuries, the bulk of uranium containing waste material has always been disposed of on the surface. Later, some of these waste disposals became settlement sites and the waste material was often used for the building and construction of houses and streets. In 1898, two years after the discovery of radioactivity by *Becquerel*, *Marie Curie* isolated the elements radium and polonium from the waste disposals in Joachimsthal in Bohemia (Czech Jachymov) [3].

In 1908-1911, the waters in the Ore Mountains were systematically investigated for radioactivity (*Prof. Schiffner*, Bergakademie Freiberg) [4]. In 1906, the first medical radon bath in the world was founded in Joachimsthal (Jachymov). 1918 saw the foundation of the radon bath Oberschlema, with the strongest radon sources in the world [1]. In 1936, in mines near Schneeberg, extensive radon measurements by *Rajewsky* confirmed the assumption (made earlier by *H. E. Müller*) of a causal link between radon and lung cancer [3]. But it was only in the early 1950s that the high dose from radon daughters to the bronchial epithelium was realized.

Postwar History of Uranium Mining in Saxony and Thuringia ("Wismut")

After the atomic bomb explosion in Hiroshima and Nagasaki in 1945, the Soviet Union intensified the research program for the production of a nuclear weapon. A feverish search for uranium ores in the Soviet empire began. Expeditions were sent to the Western Ore Mountains where deposits of pitch blend were known to exist. Explorations in existing mines in Schneeberg and Johanngeorgenstadt led to positive results in autumn 1945 [2, 5]. In April 1946, the industrial uranium mining started in Johanngeorgenstadt, later in Schlema and Schneeberg as well. In the Bohemian town of Joachimsthal, there was uranium mining even before April, 1946. On December 24, 1946, the first Soviet nuclear chain reaction was achieved by *K. Schatow* near Moscow; he used fissionable material from the Ore Mountains. On July 2, 1947, the uranium mining enterprise was entered in the commercial register at the district court

Fig. 1. A mining region in the Ore Mountains in the 1950s.

in Aue under the name "Staatliche AG der Buntmetallindustrie »Wismut« der UdSSR." It became known as the "Wismut" (a false name) [5]. The company was under Soviet military rule and the town and region of Aue were declared as prohibited areas.

In the following years, uranium production was constantly extended (Fig. 1). Since 1952, mining was also performed in regions that were not previously mining areas (Vogtland/Ronneburg).

In these first postwar years until approximately 1955, the situation was characterized by the following facts:

- Compulsory labor
- Enlistment of prisoners of war (1947: 50-60% share)
- Employment of prisoners on probation
- Volunteers as a minority
- Employment of women in mining (estimated rate 14-40% [6])
- High rate of absence, illness and accidents
- Fluctuation is elevated, escapes are common
- Cases of self-mutilation to evade forced labor

On August 20, 1953, a treaty was signed by the Soviet and East German governments that converted the Wismut enterprise from a Soviet company into a Soviet-German company (Sowjetisch-Deutsche Aktiengesellschaft [SDAG] Wismut). The working conditions improved. The company assumed a civilian character. A further extension of uranium mining into the area of Dresden took place in 1961 and 1968 [2].

As a reaction to the excessive rate of absence and accidents, and to the growing number of occupational diseases, the development of a company-based health care system commenced. This system consisted of hospitals, ambulances and convalescent homes. It was legally independent and financed by a company-owned social security organization. There was an annual routine medical check-up including chest x-ray (mobile x-ray equipment had been available since 1952-1953). A central Wismut institution for occupational medicine existed since 1968. It dealt with diagnostics in occupational diseases and gave expert opinions (except for radiation-induced illnesses). Medical care for ex-employees with lung pathology was organized in 1971 [7].

1970 to 1990 may be called years of stability: the company had a well-trained core workforce. Rules of industrial hygiene in accordance with the law of the GDR were accepted and accommodated. The limits of radiation exposure fulfilled recommendations of the International Commission on Radiological Protection (ICRP). In 1989, the penultimate year of its existence, the Wismut health care system employed 5,000 persons. Among the employees were more than 550 physicians and dentists that also acted as family doctors.

On October 9, 1990, six days after the unification of the two German states, a treaty between the Soviet Union and Germany declared the end of the Soviet-German enterprise Wismut effective January 1, 1991. On December 31, 1990, the Soviet share of the company passed into the hands of the German state. Uranium mining was generally stopped. On January 1, 1992, a Wismut successor organization was founded as a limited company (Wismut GmbH) [8, 9]. The enterprise is now assigned to the federal ministry of trade and commerce and is working on restoration of the region. The expenses of this restoration are estimated by the technical managing director of the Wismut GmbH, *Mr. M. Bergmann*, to amount to 13 billion DM for the years to come (Frankfurter Allgemeine Zeitung, March 1, 1994). The responsibility for dealing with occupational accidents and illnesses in the former GDR, including the Wismut company, was assumed by the German Workmen's Compensation Boards (gewerbliche Berufsgenossenschaften) on January 1, 1991 (*see* Chapter 8).

Economic Situation of Uranium Mining in the Former East Germany

The economic situation in East German uranium mining changed a great deal from 1946 to 1990 (Figs. 2A and 2B). In the early years, there were almost medieval conditions with a huge work force and a low productivity. As of the late 1950s, a relatively small number of trained workers had a higher uranium production. In the 1970s, mining was extended to greater depths and to deposits of smaller thicknesses. This led to higher expenses and to a reduction of productivity despite improved mechanization. Nonetheless, the GDR was number three in uranium production worldwide (Fig. 3) and the most important uranium supplier for the Soviet Union with a total of 220,000 tons of uranium [8, 9].

There are discrepant estimations regarding the number of employees in the first years of

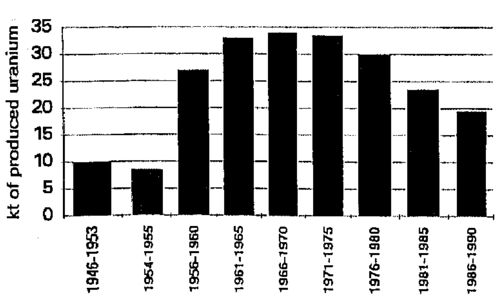

Fig. 2A. "Wismut" uranium production 1946-1990 (Data from Wismut GmbH).

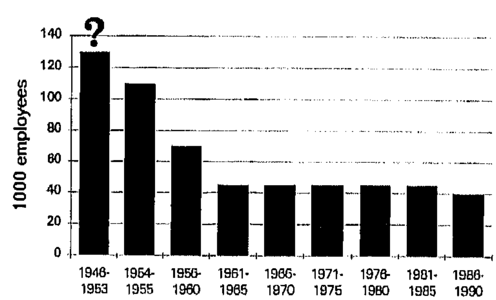

Fig. 2B. Number of employees at "Wismut" 1946-1990 (Data from Wismut GmbH).

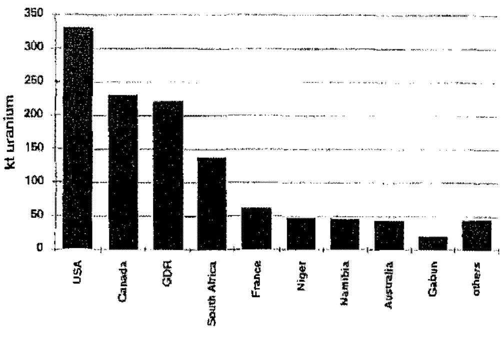

Fig. 3. Uranium production of selected countries (before 1990; without USSR [source: Bundesministerium f. Wirtschaft, Ref. f. Öffentl.arbeit, Dok. Nr. 335, August, 1993]).

East German uranium mining. *Breuer* quotes several references indicating employment of 300,000 to 565,000 persons for the year 1950 [6]. The number of employees exposed to ionizing radiation is estimated by *Schulz* to be 280,000 for the total Wismut period [10].

The Wismut company had a total surface area of approximately 37 km². The total length of shafts and roadways was 1,395 km in the late 1980s [8, 9]. In Hartenstein near Aue, the deepest shaft was 1,755 m deep. At this depth, the rock has a temperature of 60° C. Work was performed there in hot, humid air.

In uranium mining at Wismut mostly classic underground mining techniques were applied. However, the different geological conditions (ore veins in the Ore Mountains and sedimentary rock in Thuringia) required substantial modifications in the technical approach. As a consequence, there were different patterns of exposure to harmful agents for the miners resulting in a broad range of health impairments. In Thuringia, apart from underground mining, there was also surface mining with excavations more than 200 m deep.

In Königstein near Dresden, the uranium deposits were of low ore content. Therefore, a special mining technique was used, the so-called "Laugung." In this method, the rock was broken up by blasting and then sprinkled with a low concentration of sulfuric acid. With this, the uranium was extracted from the rock and the resulting solution was pumped to the surface. There the sulfuric acid was recycled and the uranium was concentrated. This method was also used for uranium extraction from waste disposals.

Fig. 4. Hauling.

Uranium Mining: Working Conditions and Profile of Exposure

The working conditions of underground mining in the Ore Mountains in the early postwar years (1946-approximately 1955) were characterized by the following features (Fig. 4):

- Drilling in rock with air floating ("dry drilling"), which led to high dust concentrations
- No forced ventilation of the mine, with a high radon concentration on the work site
- Extremely heavy work due to lack of technical aid
- Absence of industrial health and safety standards
- Poor housing and clothing conditions
- Long working hours and exhausting transportation from mine to rest camp or home

Fig. 5. Drilling.

After 1956 conditions changed for the better (Fig. 5). Artificial ventilation of the mines and drilling with the addition of water ("wet drilling") led to a lower dust and radon concentration. The concentrations of radon were systematically assessed in the mines at selected locations no earlier than 1955. The radon daughters, with their decisive contribution to the radiation dose, have been evaluated by measuring the alpha-energy concentration since 1964.

As of 1971, these data for work sites have been assigned to the individual miners using their working schedule and compliance with the annual exposure limit was checked. Systematic assessment of other harmful or stressful agents (e.g., noise, dust, vibration, heavy work, climatic conditions, etc.) has also been undertaken since the 1970s. The evaluation was used to modify working conditions and to improve the annual routine medical check-up.

The underground workers in Wismut uranium mining were confronted with a complex mixture of several harmful agents and stress factors (Fig. 6). Exposure to α-radiation is the most important health hazard, originating mostly from the radon daughters. The short-lived radon daughters are the decay product of the noble gas radon-222 (Fig. 7). Shortly after their generation in the air of the mines, they either form condensation nuclei or adhere to the dust in the air. When inhaled into the lung, they attach to the mucous layer of the bronchial epithelium. Here they disintegrate in several steps to the relatively stable lead-210, hereby emitting α- (plus β- and γ-) radiation.

To describe the accumulated α-energy exposure of miners, the historical unit "Working level month" (WLM) is used. The definition starts with the Working level (WL). One WL is the α-energy concentration of radon daughters in equilibrium with 100 pCi/l or 3700 Bq/m^3 radon. One WL is equivalent to a potential α-energy concentration of 1.3×10^5 MeV/l = 2.08

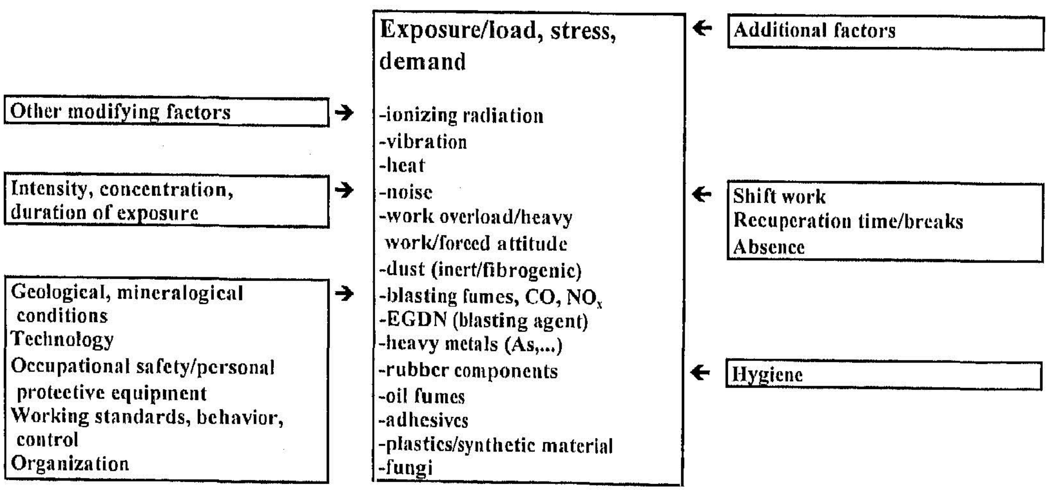

Fig. 6. A list of harmful agents and stress factors in East German underground uranium mining (together with modifying factors).

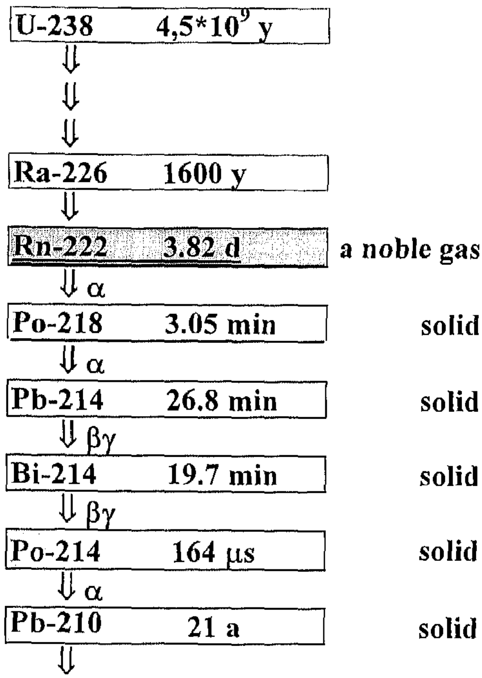

Fig. 7. Radioactive chain reactions originating from uranium-238 (half-lives of isotopes are given).

× 10^{-5} J/m³. Exposure to this concentration for one month (170 working hours) is defined as one WLM. In the GDR, a potential α-energy concentration for radon-222 progeny of 40 MeV/cm³ was allowed for exposed persons. This corresponds to an exposure of 4 WLM/year which led to a dose calculation of 40 mSv/year (in October 1993, the ICRP recommended a reduction of the dose assigned to 1 WLM from 10 mSv to 5 mSv. The annual exposure limit was reduced from 4.8 WLM to 4 WLM [11]).

Keeping this in mind, the following figures of radiation exposure in Wismut uranium mining have to be interpreted. The annual exposure is given by *Richter* as follows [quoted in 11]:

until 1955	30–300 WLM/year
1956 until 1960	10–100 WLM/year
1961 until 1965	5–50 WLM/year
1966 until 1970	3–25 WLM/year
1971 until 1975	2–10 WLM/year
from 1976	1–4 WLM/year

The quoted levels of exposure in the first 10-15 years are uncertain because they are estimations based on calculations. The evaluation of the equilibrium factors [12] in mines during those years is an important part of this calculation. The radioactive equilibrium factor characterizes the disequilibrium between the radon daughter mixture and their mother nuclide. A more precise assessment of exposure levels is performed at present on behalf of the German Workmen's Compensation Boards (Gewerbliche Berufsgenossenschaften). Existing national and international data are used, as well as simulation experiments.

The high radiation exposure in the early years of Wismut is due to the lack of ventilation in the mines and to the high dust concentrations from "dry" drilling.

The total dust concentration at miners' work sites was estimated in 1987 [Fachausschuss Staubbekämpfung der Kammer der Technik, May 15, 1987, internal communication] as follows:

1946 to 1950	50–100 mg/m³
1951 to 1954	20–40 mg/m³
1955 to 1960	10–20 mg/m³

The average figures for the postwar years are roughly consistent with results of postwar-simulation drilling experiments [*Bauer et al.*, Untersuchung zur Staub- und Schwermetallbelastung, Bergbau BG, in press]. For special working techniques, these simulation experiments showed dust concentrations substantially higher than the mentioned average. Drilling in ore resulted in total dust concentrations of approximately 150–500 mg/m³ (dependent on sample collection technique) at a ventilation rate of 0.1 m/s. Such a ventilation rate is estimated to correspond to the "natural" ventilation rate of the postwar years.

In 1987, the following exposure to total dust was estimated for underground workers other than miners [Fachausschuss Staubbekämpfung, internal communication]:

until 1950	20 mg/m³
1950 to 1960	10–20 mg/m³
after 1960	10 mg/m³

The dust in Wismut mines contains as an important factor crystalline silica. Furthermore, the dust is contaminated not only with the short-lived radon daughters, but also with long-lived α- and γ-radiating substances such as uranium-238 or lead-210. It is assumed that about 10% of radiation exposure in mines originates from those long-lived isotopes [13]. Recent experiments with simulation of postwar working techniques in

Wismut mines gave an inhalative incorporation of U-238 up to 60 kBq per year [*Seitz et al.*, BG für Feinmechanik u. Elektrotechnik (Schriftenreihe des Inst. f. Strahlenschutz), in press]. To assess the dose resulting from this incorporation, dosimetric computations were performed by *Jacobi* and *Roth* [Risiko und Verursachungs-Wahrscheinlichkeit von extrapulmonalen Krebserkrankungen..., submitted to HVBG July, 1994; published as GSF report 1994] using the new ICRP respiratory tract model [ICRP publication 66, Ann of ICRP 1994, in press]. Disintegration of an annual uranium-238 incorporation of 20 kBq (uranium in equilibrium with its progeny) in the following 50 years would result in an equivalent dose of 3 Sv to the bronchial region. In comparison, the dose from 150 WLM of short-lived radon progeny to the bronchial region would be 15 Sv.

Among the chemical substances in Wismut mines, arsenic needs special consideration as a potential health hazard in the Aue region. Indications of the level of exposure to arsenic at Wismut were given in a 1988 investigation [14]. Concentrations of arsenic particles in 77 long-time measurements ranged from 0.1 to 267 $\mu g/m^3$. Concentrations of arsenic trioxide in the air at miners' workplaces were found to be 86 to 479 $\mu g/m^3$. The maximum limit in the GDR for arsenic in air was set at 0.5 mg/m^3 for short-time exposure and at 0.2 mg/m^3 for a work shift [15].

Asbestos played a certain role in Wismut underground miners when they used special hauling techniques. Smoking was very common among Wismut miners. Yet, an individual smoking history was recorded no earlier than in the 1970s.

Occupational Diseases in Uranium Mining

The exposure to a complex variety of potentially harmful agents and stress factors leads to manifold stress or strain reactions in the human body (Fig. 8).

Figure 9 shows the profile of exposure for Wismut underground uranium miners with the corresponding organ systems.

In the assessment of radiation-induced health impairment, the Wismut company confined itself to an evaluation of morbidity. Investigations of radiation effects at a cellular or subcellular level remained sporadic. An internal Wismut study from 1965 examined the blood count in 1,807

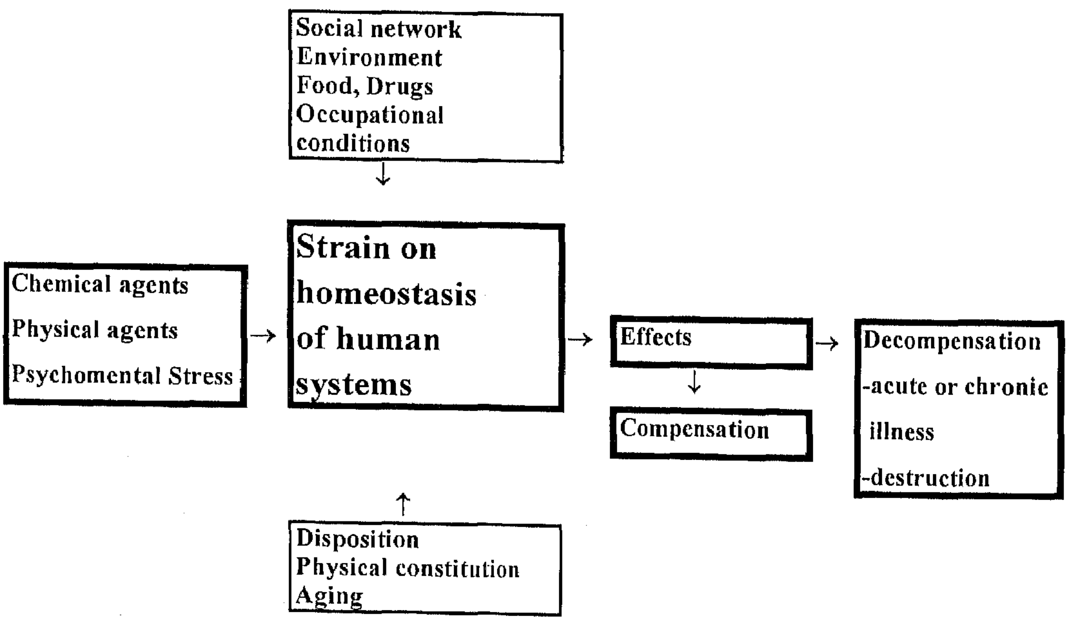

Fig. 8. Stress and strain reactions, and resulting health consequences (schematic).

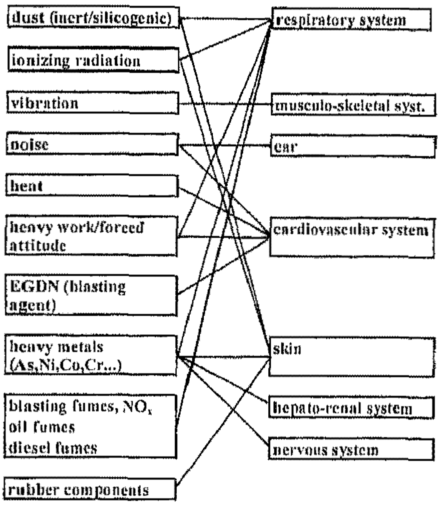

Fig. 9. Profile of exposure and corresponding organ systems in East German underground uranium mining (schematic).

miners, partly including reticulocytes and differential blood count, and found no deviation from the normal values [16]. Chromosomal aberrations in uranium miners have been described in literature [17]. In Wismut miners, an attempt for such an investigation was made in the 1980s; positive results are not known.

Although the acknowledgment of occupational illnesses bears some elements of convention through legal regulations, the rate of such compensable occupational diseases does reflect exposure to harmful agents and the consequent strain to the human organs. A synopsis of compensable occupational illnesses in Wismut uranium mining is given in Table I for the period 1952-1990, and in Table II for 1987-1990 (from annual records of occupational diseases at Wismut, formerly confidential data; *see* also [18]). The crucial component is the pulmonary morbidity. The causation of lung cancer by radon progeny (Schneeberg lung disease) is established by several epidemiological studies in various mines throughout the world [19-21]. Eleven studies have been summarized recently in a meta-analysis by *Lubin* [22]. The result is an excess relative risk for lung cancer per unit of cumulated exposure (ERR/WLM) of 0.49% (95% CI: 0.2-1.0%).

In Wismut miners, more than 95% of all bronchial carcinomas (and silicosis) correspond to exposure from 1946 to 1957. Again, this shows the extreme working conditions in the postwar years. For bronchial carcinoma, these statements are confirmed by a recent descriptive analysis of 93 lung cancer cases in former Wismut miners, evaluated from 1991-1993 by *Wichmann* [23]. In most of these cases, the employment in the Wismut company dates back to the early postwar years. The median for the duration of employment underground is three years. A working period of three years during the early years of Wismut would, according to Richter, correspond to an exposure of approximately 500 WLM [11]. According to the mentioned meta-analysis by *Lubin* [22], this causes

Table I. Compensable occupational illnesses in "Wismut" uranium mining 1952-1990 (from formerly confidential Wismut data)

DDR Code Number of Occ. Illn.	BRD Code Number of Occ. Illn.	Illness	Absolute Number	%
BKVO/DDR	BeVO/BRD			
40	4101/4102	silicosis, silicotuberculosis	14733	47.8
92	2402	Schneeberg lung disease	5276	17.1
54 71-72	2103/2104 –	vibration damage vertebral column disease	4950	16.0
50	2301	occupational hearing loss	4664	15.1
80	5101	skin disease	601	1.9
		others	628	2.1
		Total	30852	100

Table II. Compensable occupational illnesses in "Wismut" uranium mining 1987-1990 and percentage of approval (from formerly confidential Wismut data)

DDR Code Number of Occ. Illn.	FRG Code Number of Occ. Illn.	Illness	Absolute Number	%
BKVO/DDR	BeVO/BRD			
92	2402	Schneeberg lung disease	804	38.2
40	4101/4102	silicosis, silicotuberculosis	676	32.1
54	2103/2104	vibration damage	411	19.5
70	2110	vertebral column disease	72	3.4
80	5101	skin disease	49	2.3
50	2301	occupational hearing loss	30	1.4
27	1309	card. arrh./nitric acid ester	12	0.6
93	4104	asbestos cancer	10	0.5
41	4103	asbestosis	7	0.3
So.E.		sclerodermia	12	0.6

an excess relative risk of 250%. In other words, the lung cancer risk would be enhanced by a factor of 3.5. In the quoted descriptive analysis [23], 91 out of the 93 lung cancer patients were smokers or ex-smokers. Generally, a good knowledge of the interaction between radon progeny and smoking in lung cancer causation is essential. At present, a synergism somewhere between additive and multiplicative is generally assumed in the literature [20].

Selig et al. investigated 135 cases of bronchial carcinoma that were observed in 52,402 male employees at the Wismut company between 1985 and 1989 [24]. They found a multiplicative effect of the combination of underground working plus smoking. The risk was enhanced by a factor of 8.5 compared to nonsmokers working above ground.

Silicosis and silicotuberculosis are well-known consequences of exposure to crystalline silica. In a trend analysis by *Mehlhorn* and *Friedrich* dating from 1990, there was no evidence for new cases of silicosis corresponding to a Wismut mining exposure after 1961 [*Mehlhorn* and *Friedrich*, unpublished data]. A pronounced fall in the prevalence of silicosis in former Wismut miners can be expected for the next years. There were 5,604 cases of silicosis in the year 1990. The prognosis for the year 2000 is approximately 2,500 cases.

While the criteria for acknowledgment of silicosis as an occupational disease were comparable in East and West Germany, this is not true for the acknowledgment of bronchial carcinoma. In interpreting the number of bronchial carcinomas in Table I and II, one has to keep in mind the following facts. For the Wismut miners in the GDR, bronchial carcinoma was regularly acknowledged as a compensable occupational disease at an exposure level above 450 WLM. Below this exposure level of 450 WLM, additional criteria were evaluated such as simultaneous manifestation of silicosis, duration of underground work, latency period and results of histological examinations. The acknowledgment was always rejected below an exposure level of 200 WLM. Smoking habits were not considered. In the early 1980s, attempts to lower the level of acknowledgment were not supported by the administration. However, in 1990 they were accepted.

According to the law in the Federal Republic of Germany (FRG), a fixed threshold for the acknowledgment of occupational diseases is not used. Instead, there is an individual evaluation by experts. As a guideline in this evaluation, a model by *Jacobi et al.* (1992) allows the computation of the probability of causation of lung cancer by occupational radiation exposure in uranium mining [12]. The re-evaluation of cases that were rejected before 1990 became necessary and will increase the case numbers given in Tables I and II. For the present period, *Breuer* estimates 200 to 300 new cases each year [6].

In the literature, there are indications for an enhanced lung cancer risk per unit exposure at a lower exposure rate [22]. The risk is also dependent on age at exposure and time since exposure [12, 20, 25]. Future long-term epidemiological studies of cancer prevalence in former Wismut miners employed in later years with lower exposure should result in a better knowledge of the effects of low-dose radiation.

The contribution of silica to the causation of lung cancer is difficult to assess. Crystalline silica is a frequent agent in uranium and other mines worldwide. Some investigators attribute carcinogenic properties to silica [26, 27] while others do not find evidence for lung cancer risk from crystalline silica [28]. Exposure to silica can cause silicosis. Silicosis is described by some authors as a risk factor for lung cancer [29]. Other investigators find no association between the two diseases [30]. At Wismut, *Mehlhorn* reported a high rate of bronchial carcinoma in miners with known silicosis [31].

Even the so-called "inert" dusts are said to represent a danger to health. A biological effect is assumed that is neither fibrogenic, carcinogenic, toxic nor allergenic. Instead, an overcharge of protective and scavenging mechanisms of the lung is assumed.

Arsenic could contribute to lung cancer causation in uranium mines. At Wismut, arsenic is found in the Aue region. The occupational causation of lung cancer by arsenic is well-known for copper smelters [32]. For miners [33] and especially uranium miners [22], the epidemiological data base is less solid. Clear indications of a synergism between radiation and arsenic in uranium mines are not known, nor has such a synergism been shown in animal experiments [34].

Extrapulmonary cancer was not a compensable occupational disease in Wismut miners. In the literature, no clear and significant exposure-morbidity relationship is described [35 and *S. Darby et al.*, submitted]. Indications of an elevated rate of larynx carcinoma in Wismut miners were evaluated in the late 1980s, but the investigations could not be brought to a definitive result. *Fritzsche* reported four cases of basalioma which were accepted as compensable occupational diseases [14]: they were interpreted as malign neoplasms of the skin caused by arsenic. Yet, Czech authors describe basaliomas in uranium miners as radiation-induced [36]. *Jacobi* and *Roth* are working on a dosimetric approach for the estimation of the risk of extrapulmonary cancer at the Wismut [*Jacobi* and *Roth*, Risiko und Verursachungs-Wahrscheinlichkeit von extrapulmonalen Krebserkrankungen..., submitted to HVBG July, 1994; published as GSF report 1994]. For this, they use the risk coefficients for extrapulmonary cancers observed among the atomic bomb survivors.

Interstitial lung fibrosis was reported in East German miners exposed to radon progeny in nonuranium mines [37]. In six cases, lung fibrosis was acknowledged to be caused by a high exposure to radon progeny combined with simultaneous dust exposure. In contrast, lung fibrosis was not acknowledged to be radiation-induced at the Wismut company.

The data in radiation-exposed miners are as yet incomplete or not evaluated with respect to possible health impairments other than the ones described above. Since there is a significant exposure in uranium mines not only to α-radiation but also to external γ-radiation, other health impairments of a chronic, non-neoplastic nature may be expected (e.g., premature aging and consequences of impairment in the immune and hemopoietic system).

Present Situation and Research Activities

Managing the manifold problems that arise from uranium mining in the former GDR is a challenge for politics, economy and science in Germany. Apart from the restoration and redevelopment of the region, the future medical care for the former Wismut miners also has to be organized. Therefore, in 1992 the Workmen's Compensation Boards in Germany (Gewerbliche Berufsgenossenschaften) set up a coordinating agency, Zentrale Betreuungsstelle Wismut (ZeBWis). The first task for this agency was the determination of the names and addresses of the living ex-miners [38]. A regular detailed medical examination is offered to the former Wismut employees as an option for early diagnosis of work-related diseases [39]. In the case of disease manifestation, the evaluation of possible occupational causation relied on an individual assessment of exposure conditions. However, the levels of exposure to potentially harmful substances are not well known for the postwar years. Therefore, the Workmen's Compensation Boards have started a determination of the working conditions in those early years. For this, existing data are evaluated and at the same time new measurements and simulation experiments are performed. Apart from investigations of exposure conditions, morbidity and mortality of surviving Wismut employees are also analyzed. The synopsis of this information can improve our knowledge of causation of occupational disease, especially in the field of low-dose radiation. Combined effects of radiation and toxic chemicals are another area of interest [40]. The existing studies concerning lung cancer caused by radon progeny in mines are based on 2,700 fewer cases [*Lubin*], while in Wismut miners, there is already a database of more than 6,000 disease cases.

However, even after improvement of epidemiological knowledge, we will still be confined to general risk assessment (probability statements) [41]. For an individual prognosis, biological markers of health impairment could be used [42]. Biological markers of exposure ("biological dosimetry" techniques) are also required, as the reconstruction of this exposure from the working history is not always feasible. The Workmen's Compensation Boards (representing the German Occupational Accidents' Insurance System) are funding research projects for the assessment of biological indicators of ionizing radiation in Wismut miners.

The possible cancerogenity of silicogenic dust is planned to be examined in another research project by the National Institute for Occupational Safety and Health (NIOSH) and the National Cancer Institute (NCI) using the Wismut data. Research groups at the German cancer research center (DKFZ) are working on archives for the pathology of lung cancer in Wismut employees. A reclassification is intended, combined with the evaluation of reference standards of lung pathology.

Summary

Underground uranium mining in East Germany at the Wismut enterprise from 1946 to 1990 is an important historical example of a considerable chronic exposure to radon progeny for several hundred thousands of people. Exposure was highest in the early postwar years. Between 5,000 and 6,000 cases of bronchial carcinoma are already accepted as compensable occupational diseases to date. Estimations for the total number of lung cancer cases in Wismut mining reach a number of 10,000 or more. A special feature of Wismut uranium mining in the early postwar years is the exposure to very high dust levels and to considerable concentrations of long-lived α-radiating substances such as uranium-238 and others. Furthermore, the possible contribution of toxic chemicals, such as arsenic and silica, and other factors to miners' morbidity needs careful pathophysiological consideration. The extensive data from Wismut uranium mining could improve our understanding of such a complex exposure situation resulting in a variety of health impairments other than lung cancer.

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