CONTRASTS BETWEEN THE ENVIRONMENTAL RESTORATION CHALLENGES POSED BY URANIUM MINING AND MILLING IN THE UNITED STATES AND THE FORMER GERMAN DEMOCRATIC REPUBLIC

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ABSTRACT

The former Soviet Union demands for uranium feed materials were primarily met by the East German Republic. A small area 200 km long and 50 km wide in the provinces of Saxony and Thuringia provided more than half of the uranium concentrate processed by the Soviet Union, and used for nuclear weapons development and power generation. With the majority of the ore processed in Germany of an average lower grade than a number of deposits found around the world, the mining and milling resulted in an enormous scale of surface disturbance and quantities of mill tailings concentrated in a relatively small densely populated geographical area.

As a result of the re-unification of the two Germanies, all uranium extraction and processing activities were suddenly brought to a halt for economic reasons. The former Soviet-East German corporation responsible for the uranium concentrate production was changed into a German state-operated company tasked with the facility decommissioning and environmental restoration. Code-named WISMUT (the German word for Bismuth) during the cold war, this organization was literally changed overnight from a self-sufficient, autonomously operating and state controlled effort into a public works, environmentally conscious corporation.

Faced with such a large scale environmental restoration challenge and with a lack of experience in environmental reclamation by western standards, there have been problems identifying environmentally and economically acceptable solutions in the short time since the re-unification and cessation of production. While the un-remediated areas continue to pose some degree of risk to human health and the environment, the debate over the nature of the solutions has been intense and substantial progress has been made.

This paper presents a description of the former East German uranium mine and mill environmental restoration challenges. It describes the current environmental setting and contrasts the U.S. program (both Title I and Title II) compliance with prescriptive standards versus the German initiative to establish a more risk-based regulatory structure for mine and mill restoration as in other uranium producing countries.

INTRODUCTION

As the chapter on the Cold War between world superpowers closes, many communities around the world are faced with an environmental legacy of enormous quantities of low-level radioactive materials from the production of uranium used for both energy and nuclear weapons. The United States obtained about 2/3 of its uranium from reserves within its own western states. The former Soviet Union obtained its uranium from a variety of sources, with the majority derived from mines and mills in the former German Democratic Republic (East Germany).

With the re-unification of Germany and the dissolution of the Soviet Union, the former East German production of Uranium essentially ceased in 1991. Since the re-unification, the German Government has taken steps to plan for the rehabilitation of areas used for uranium production (1, 2, 3). The United States and Germany have many parallels in the environmental restoration challenges faced by the two countries. However, the differences are important and should be made more widely known. This paper presents a description of the closing setting of the two uranium production industries in the two countries, and contrasts their respective environmental restoration problems.

History of German Uranium Mining and Milling

In order to understand the current environmental setting, it is instructive to review the history of the uranium production industries in the two countries. Some readers may be *familiar* with the uranium mining and milling portion of the nuclear fuel cycle in the U.S. However, few understand the analogous industry in the Soviet Union. At the end of World War II, Russia, and the associated republics which would come to be known as the Soviet Union, moved quickly to develop a nuclear capability. The hydrothermal vein deposits near Aue in the Saxony Province of East Germany were known to contain high percentages of uranium, and underground mining of high-grade materials began almost immediately after the war. Exploration was facilitated by the presence of existing underground mines, which had been producing silver and other metals (e.g. Sn, Bi, Ni and Co) since medieval times.

In 1946, the Wismut Corporation was formed as a totally Soviet-owned stock company (SAG Wismut). The name: Wismut, was chosen as a "code" name (in a manner similar to the US method of disguising names of secret operations - like the "Manhattan Engineer District"). In german, "Wismut" is the word for the metal, Bismuth. Exploration across the southern area of East Germany was begun and production of uranium (early on as hand-selected pitchblende concentrate and later as yellowcake - U308) was initiated. Uranium concentrate was shipped to the Russian interior for further processing and enrichment as early as 1947. In 1954, the Wismut Corporation was converted into a joint Soviet-German stock company (SDAG Wismut), with equal shares held by the USSR and the former German Democratic Republic.

Similar to the earlier U.S. program, the Wismut operation was shrouded in secrecy under the guise of national security. However, unlike the U.S. uranium production industry, the Wismut program received its operating funds from the government, and free market economics were never allowed to dictate how the operation matured. By the end of the sixties, the Wismut Corporation employed almost 100,000, and was effectively self-sufficient, with facilities and infrastructure including transportation services, worker and family care and feeding (including health care), etc.

The uranium mineralization in the former East Germany was found in a relatively small area in an east-west band 200 km long and 50 km wide along the Czechoslovakia - German border as shown in Fig. 1. Viable mining was performed in five different geologic settings. Table I presents the approximate amounts of Uranium mined from each type of deposit along with the amount of ore processed (4). Note that the first two of these deposits resulted in over 80% of the total uranium produced in Germany.

TABLE I
Uranium Production in Germany by Geologic Source

Ore Source	Uranium Derived (%)	Average Grade (%)	Uranium Derived (tons)	Ore Milled (Mt)
Ronneburg Black Shale	45	0.085	99000	127
Aue Vein Hydrotherma	41	0.4	90200	25
Sandstone	8	0.11	17600	17
Carbonates	5	0.07	11000	17
Uraniferrous Coals	1	0.095	2200	3
Totals:	100		220000	188

History of US Uranium Mining and Milling

In the United States, the history of the uranium production industry can be divided into three periods. Prior to 1940, uranium was produced as a minor commercial commodity. Almost overnight during World War II, its military importance made uranium exploration and production literally explode. During the early sixties, uranium production for peacetime nuclear-powered electrical generation again brought a surge in exploration and production capacity.

The fourties military demand was met from known sources of supply with most uranium coming from Belgian Congo pitchblende and the Grèat Bear Lake deposit in Canada. These sources were supplemented by production from treatment of previous tailings left over from earlier rare

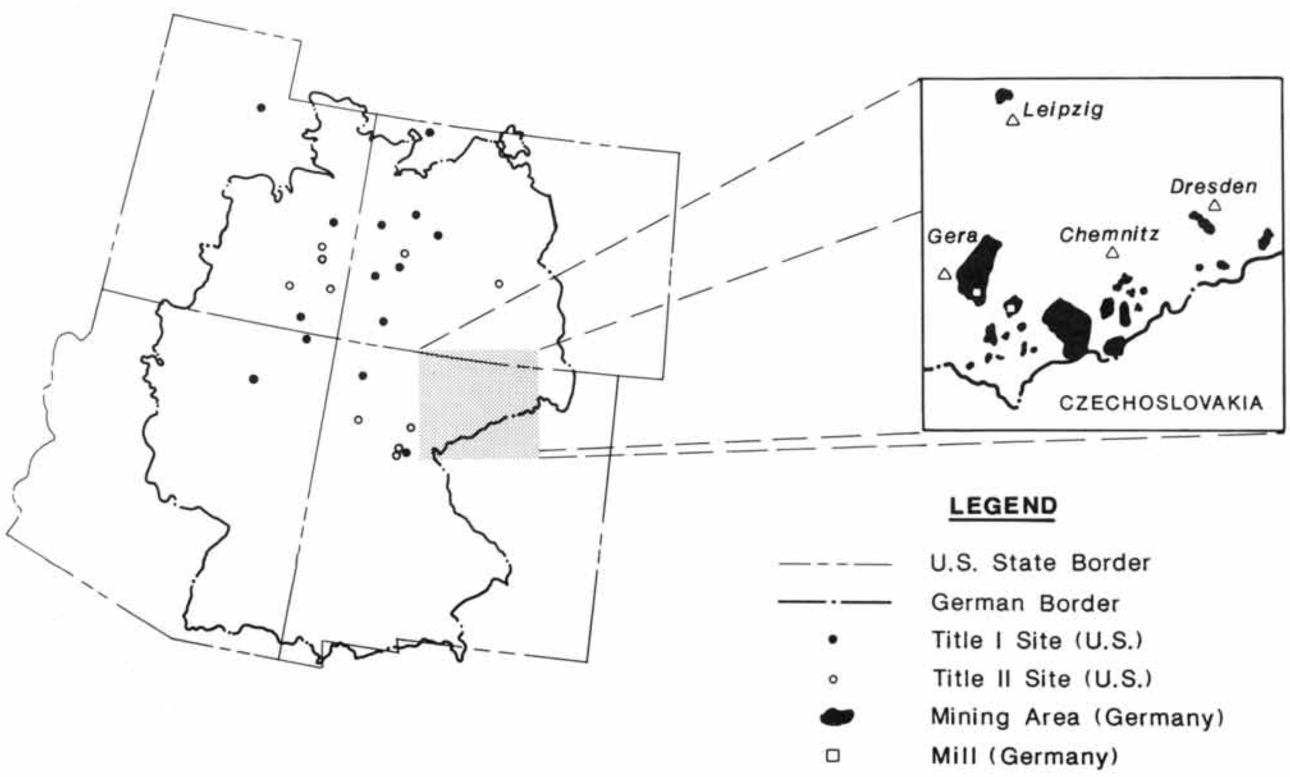

Fig. 1. Geographic comparison of U.S. and German Uranium production areas.

metals extraction facilities and several small new mines in the Colorado Plateau area. The extraction processes used were essentially those developed at the turn of the century with recovery relatively low compared to modern methods.

The United States enacted the first legislation for the control of the uranium production industry with passage of the Atomic Energy Act (AEA) of 1946. This precipitated research efforts to improve extraction processes and eventually led to the use of lower-grade sources than considered practical before. The 1946 AEA (and its amendment in 1954) did not include provisions for environmental restoration of production facilities. In the United States, uranium production was encouraged by incentives such as government provided ore stations, access roads, hauling subsidies, bonuses and a guaranteed fixed price for U.S. Government purchases. This resulted in a surge of exploration and production leading to the peak years of 1960-1963, with an annual production of about 15,000 metric tons of uranium concentrate extracted from about 7 million metric tons of ore per year in this 3-year period.

By the end of the fifties, most large ore reserves had been identified, and in 1958, the U.S. Government canceled its agreement to purchase future uranium from ore reserves as yet unidentified. This removed the incentive for further exploration and eventually led to many mill shutdowns as their contracts with the government expired. By the early seventies, mining and milling was conducted by private industry, with free market economics dictating the supply and demand of uranium concentrate. Most of the facilities which had produced uranium concentrate for the U.S. Government had been shut down and abandoned. Facilities still commercially producing uranium under contracts with the nuclear power plant industry continued operation well into the seventies.

Through 1979, the total uranium production from sources in the U.S. is estimated at about 280,000 metric tons, extracted from about 150 million metric tons of ore. During the seventies and eighties, the U.S. uranium industry steadily declined until the present day with only a few relatively small active sites operating. In 1991, only two conventional mills operated, producing less than 1,100 metric tons of uranium and 550,000 metric tons of tailings (5). This can be attributed in large part to nuclear power plant cancellations or deferments, leading to lower uranium demand and lower prices. At the same time, environmental restoration costs have continued to climb leading to increased reliance on uranium imports. The number of active and inactive milling facilities within the U.S. over the last 50 years is shown in Fig. 2 (6).

The uranium in the U.S. was found in a variety of geological settings and the uranium extraction industry developed a wide diversity of both mining and milling facilities. Mills tended to be located in river valleys near small to medium-sized communities because of the availability of water and a stable work force. The mines providing ore to these mills tended to be numerous and in most cases, substantially removed from the mills. In addition, the mine operators generally were not captive to the mill operators. Free market economics were allowed to dictate the best market for the ore provided by most mines. Therefore, the tailings left behind at most mill sites contain residual materials from processing ore from many sources.

GERMAN URANIUM MINING AND MILLING INDUSTRY DESCRIPTION

Because the uranium mineralization was localized to a relatively small area in the southern part of East Germany, the mining and milling developed into a small number of very large facilities. Indeed, over 80% of the uranium ore processed in Germany came from just two unrelated deposits (Ronneburg near Gera, and Aue). In addition, over 95% of all the tailings produced during milling were deposited at just two mill sites (Seelingstadt and Crossen). Table II shows all of the major disturbed areas and volumes resulting from uranium production in Germany. It includes both the mining waste rock, as well as tailings.

Several much smaller mills and many smaller mining sites than described in the following sections were abandoned by the Wismut organization very early on. On the basis of former East German legislation, these areas (quite small compared to the current Wismut operations), became the responsibility of the communities and companies who now have ownership. More discussion of these "commercial" restoration challenges is provided in the discussion under "Regulatory Concerns" after the following description of the German uranium industry:

TABLE II

Major Disturbed Areas and Volumes from the German Uranium Production Industry (tailings impoundments and waste rock piles).

	Disturbed Area (ha)	Volume (Mm^3)
Crossen Tailings	250	45
Crossen Plant/Ore	22	2
Seelingstadt Tailings	335	107
Seelingstadt Mine Waste	520	60
Ronneburg Mine Waste	620	188
Schlema Mine Waste	311	45
Konigstein Mine Waste	27	3
Total	2085	450

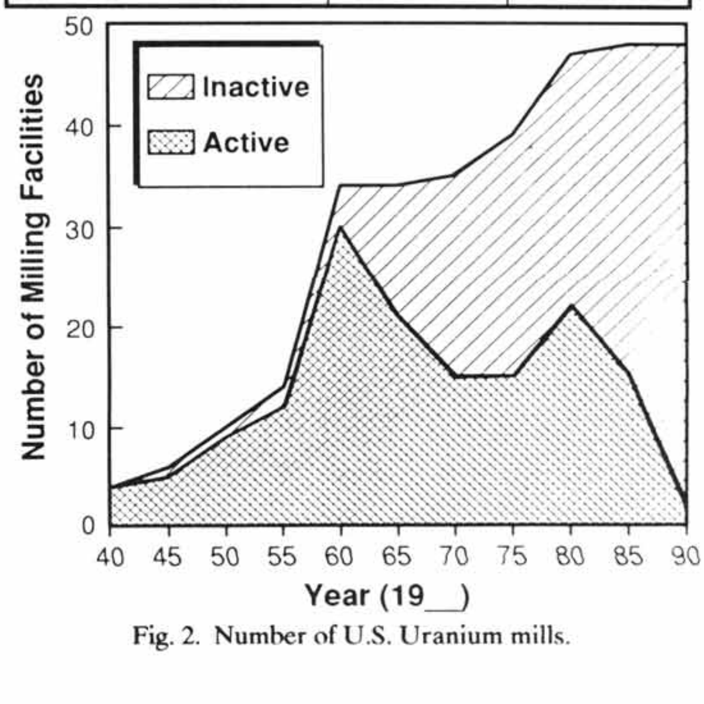

Fig. 2. Number of U.S. Uranium mills.

German Open Pit Mining

Open pit mining methods produced only 12% of the uranium produced in Germany (26,000 metric tones), but accounted for about 20% of ore processed (40 million m ^ 3), and almost 600 million m ^ 3 of mining-related material removal (ore and waste). These figures include current major Wismut sites as well as old sites abandoned in the fifties. Of this, over 170 million m ^ 3 was removed from a single open pit mine (producing 19,000 metric tons of uranium) near the city of Gera, in the province of Thuringia. With a depth of 240 meters and plan area of over 160 ha, the Lichtenberg open pit mine in the Ronneburg mining district could be considered to be comparable to the largest U.S. open pit uranium mine: Jackpile - 60 km west of Albuquerque, New Mexico, with a total mined volume of about 300 million m ^ 3.

The Lichtenberg open pit mine was developed in a vast ore body. Mining began underground and continued until about 1957. Waste rock was brought to the surface and placed in piles nearby. Because of the high carbon and sulphur content of the black shale deposits (some waste rock contained up to 15% sulphur and carbon), underground fumes and fires forced Wismut to open pit removal which operated from 1957 through 1978. Even while open pit methods were being employed, additional underground works were opened. When the pit became too deep to manage air quality concerns from truck exhaust and radon, the open pit mining ceased. With better fire prevention methods, underground mining methods were resumed. The open pit was also employed for underground mine waste disposal during the later years. This waste rock deposition reduced the total pit volume from a production maximum of 160 million m ^ 3 to the current volume of slightly more than 80 million m ^ 3.

A few other much smaller open pit mines were employed in the early years of production. The most notable were at the present site of the Seelingstadt uranium mill about 25 km northwest of the city of Zwickau and 15 km southeast of Gera (the two are called Culmitsch and Trunzig - totaling 18 million m ^ 3 of mining-related material removal), and which have been completely filled in and covered with tailings from subsequent milling of ores brought to the mill site mainly from the Ronneburg mines.

German Underground Mining

The vast majority of uranium produced by Germany was derived from ore from underground mines. Approximately 150 million m ^ 3 of ore was mined along with about 150 million m ^ 3 of mine waste. Most of this ore was removed from the Ronneburg black shale deposits (same ore body as the Lichtenberg open pit mine) in Thuringia and the hydrothermal vein deposits near Aue in Saxony. As shown in Table I, over 80% of the uranium produced came from these two deposits alone.

The waste rock from underground mining was usually piled just outside mine-shafts. Little or no effort was made to replace this material into exhausted mine volumes. The resulting waste rock contains small (but significant due to the total amount of waste) amounts of radioactivity as unprocessed low grade uranium ore with its natural series daughters.

At the Ronneburg mining area, over 100 million m ^ 3 of waste rock has been piled nearby (from both open pit and underground mining), in addition to the 80 million m ^ 3 already back-filled in the open pit. Near Aue, in the Erzgebirge Mountains, the underground mine waste has been placed in 42 piles covering an area of 311 ha and comprising a volume of over 45 million m ^ 3. About a dozen other much smaller nearby mining areas in the Erzgebirge resulted in associated waste rock piles with a combined total volume of less than 10 million m ^ 3.

Conventional Milling Processes in Germany

Apart from seven small mills abandoned in the fifties and early sixties, essentially only two conventional milling facilities were used by Wismut to process virtually all uranium ores (Seelingstadt and Crossen). Both of these facilities were modified over time, to accommodate the primary source of the feed ore, as well as state of the art in milling technology. While the Crossen mill used only alkaline leach methods, the Seelingstadt facility employed acid and alkaline leach processes in parallel. Both mills (within about 30 km of each other) were centrally located along Wismut rail transport systems to facilitate ore delivery and product distribution.

The present facility at Seelingstadt was started in 1960 and replaced several smaller mills at the same site. Two nearby tailings piles were created: Trunzig and Culmitsch (19 and 85 million m ^ 3 respectively). Both tailings disposal areas were operated with two primary piles used for materials management. In addition, both areas were formed in and over former open pit uranium mines. The mine spoils from the earlier mining were placed adjacent to the pits, and were subsequently used for dam materials during tailings placement. The Seelingstadt mill primarily processed ore from the Ronneburg mining area (although some ore from other deposits was processed there too).

The mill at Crossen began processing in 1950. Almost all of the high grade hydrothermal vein ore from Aue was processed at Crossen, and like the Seelingstadt mill, it also processed ore from other deposits as well. At Crossen, over 90% of the resulting tailings are held in a single pile (over 40 million m ^ 3, with a maximum depth of 50 meters), which contains over 4 million m ^ 3 of standing water, at depths up to 17 m and covering an area of 100 ha.

A line drawing with the Crossen tailings piles and nearby villages is shown in Fig. 3. In order to illustrate the magnitude of scale difference with a typical U.S. tailings pile, a drawing of the Title I mill site which was located at Durango, Colorado prior to relocation is superimposed to scale within the outline of the Crossen pile. Note the difference in size. The total tailings material relocated from the Durango piles was about 2 million m ^ 3, which represents the average U.S. Title I mill tailings pile size (Title II piles tend to be about 2-3 times larger, but still small compared with the two major German piles). The Durango piles were placed against the side of a mountain with a comparable depth to the tailings at the Crossen site. Note the similar proximity of nearby population at the two sites, schematically illustrated by roads and houses.

Heap and Underground Leaching in Germany

In the latter years of operation, Wismut began uranium recovery using heap leaching at the Ronneburg mining area using waste mining rock of a higher grade. When the decision was made to cease production operations, a single (but very large) heap leach pile was being processed. With a volume of 7 million m ^ 3, this single heap leach pile is the largest one in the world known to the authors.

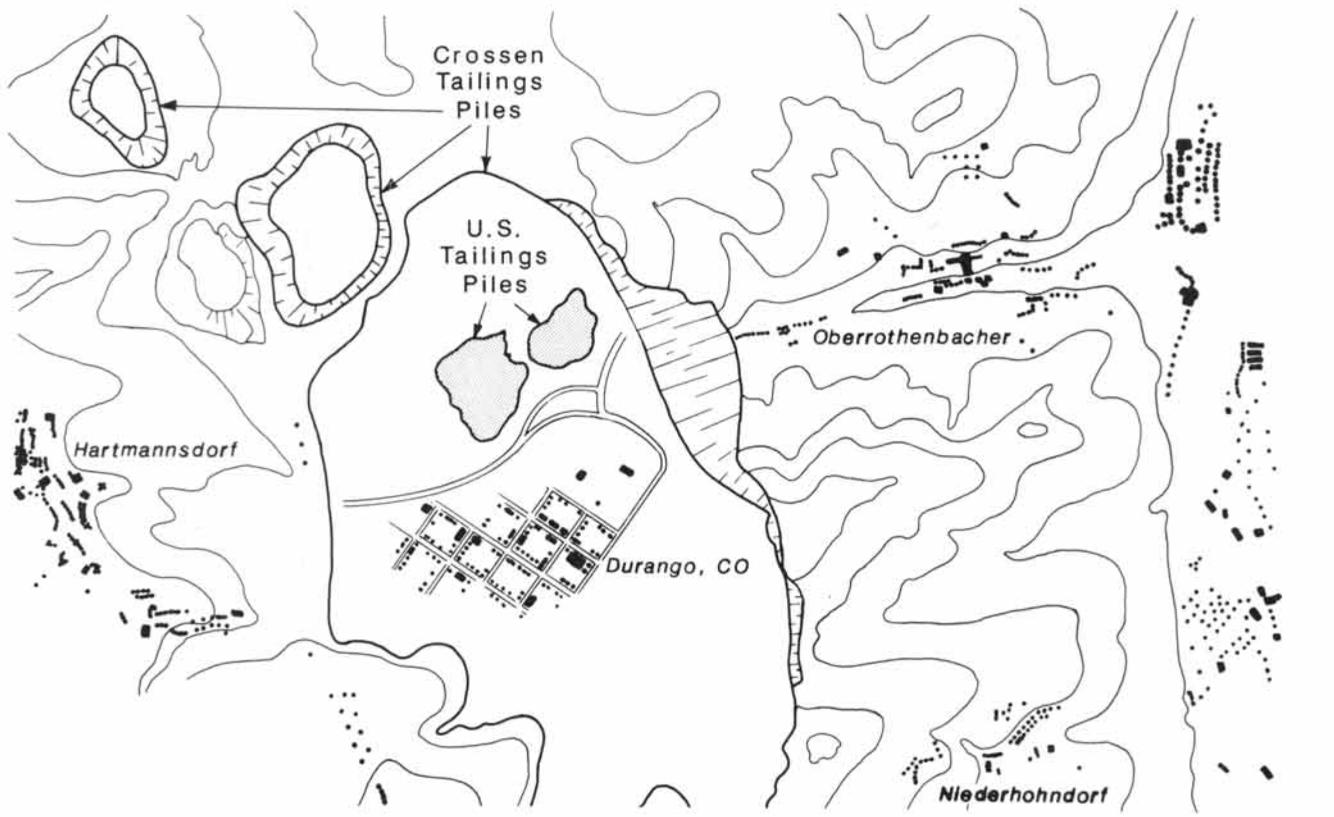

Fig. 3. Typical U.S. Title I tailings piles superimposed on the Crossen Pile.

Another Wismut facility at Konigstein (south of Dresden) is worth mention. With ore production starting in 1967 using room and pillar methods, the Konigstein facility represents one of the most modern of the East German production facilities. By 1980, a decision was made to switch to underground leaching. This method used underground mining methods to rubblize blocks of ore (as large as 100m x 100m) and inject sulfuric acid into the rubble while still underground. Using gravity flow and the in-situ dip of the confining layers, pregnant liquor was collected and pumped to the surface where chemical precipitation methods were used to concentrate uranium. The resulting intermediate grade concentrate was then shipped to the Seelingstadt mill for further processing. The mine waste rock was placed in piles near the underground access, and higher grade waste was used for above-ground heap leaching.

REGULATORY CONCERNS

In the United States, regulatory structure for uranium mill restoration was first introduced in the early 1970's. While some states imposed local restrictions and requirements on uranium milling, it wasn't until 1977, with the passage of the Uranium Mill Tailings Radiation Control Act (UMTRCA) by Congress, that significant regulatory structure was imposed. Even with UMTRCA in effect, requirements on mining activities were few and inconsistently applied. This was primarily because most were already in operation when new requirements were enacted, and many were "grand-fathered".

However, UMTRCA did place very specific requirements on the uranium milling operations, and included provisions for restoration of even the older abandoned mills. All known uranium milling facilities were grouped into two categories. Those facilities which were abandoned (which also primarily produced uranium under contract to the U.S. Government) were covered under Title I of UMTRCA. Those facilities which were still in operation (some of which still had contracts with the U.S. Government) and were operated by private companies were regulated under Title II. These facilities came to be known as Title I and Title II mills, respectively. Fig. 4 shows the total tailings volumes of all U.S. uranium mill tailings by State according to whether restoration is the responsibility of the U.S. Government (Title I) or the responsibility of the current industrial (Title II) owner (5). Note that over 2/3 of the tailings volume in the U.S. is being restored by the current (private) owners.

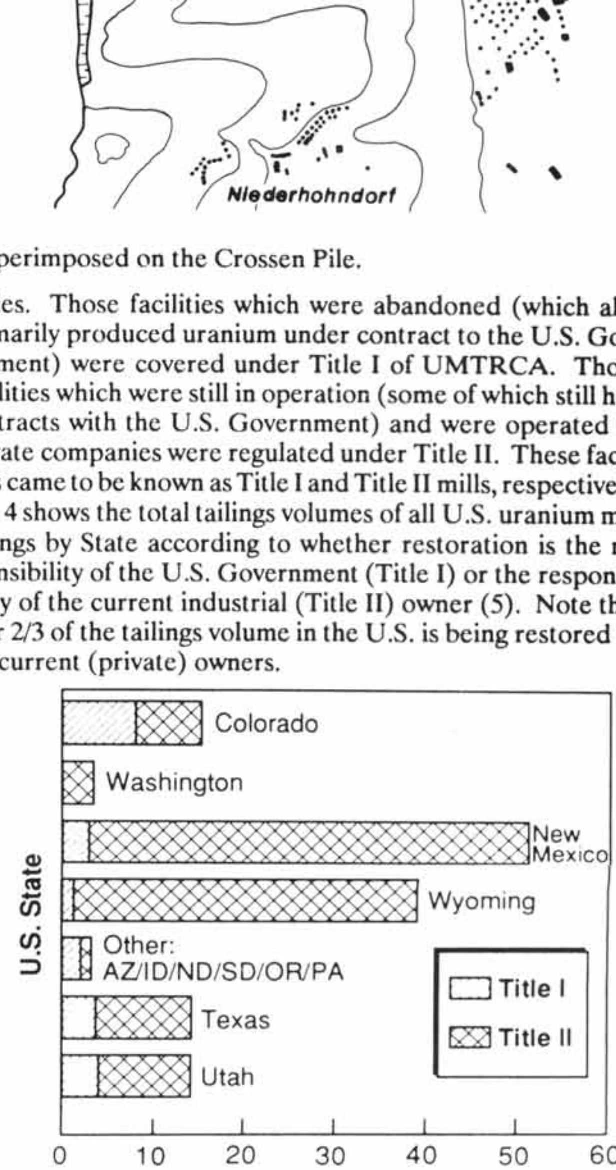

Fig. 4. U.S. uranium tailings volumes.

Title I required the Department of Energy (DOE) to acquire the abandoned facilities and environmentally restore them. Title II owners were required to post bonds and environmentally restore their facilities when milling operations ceased. The U.S. Environmental Protection Agency (EPA) was directed to establish prescriptive clean-up standards with an adequate margin of safety to protect human health and the environment. The U.S. Nuclear Regulatory Commission (NRC) was directed to license and certify that the clean up and stabilization efforts under both Titles were completed. Once the residual radioactive materials at the mill sites had been stabilized, the DOE was given responsibility to maintain the isolated materials in perpetuity. The Title II sites are being remediated by the private owners, however at their completion and concurrence (by NRC and the affected States), these sites will be transferred to the DOE for long term care and maintenance.

The primary motivation for enactment of UMTRCA in the U.S. was the concern over doses to nearby populations (and the fact that tailings materials had been used for construction purposes at literally thousands of private properties). In the Final Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites (October, 1982), the EPA estimated that between (depending on the risk model used) 130-150 fatal cancers per 100 years would be attributable to exposure of local and regional populations to all the inactive (Title I) tailings sites if no restoration was performed. The primary contribution to these risks was from radon daughter inhalation (both in private properties with tailings used for construction and in ambient air released from the un-stabilized piles). A small contribution from particulate originating from wind erosion of tailings was also included.

While groundwater contamination was recognized in the vicinity of the tailings piles, consumption by local populations was undetermined, but deemed to contribute only a small fraction of the risk from inhalation. Therefore, EPA initially set clean-up standards primarily on the basis of Ra-226 as the source of radon and subsequent daughter products (7). It also introduced requirements on the longevity of any disposal method, arguing that a 200-1000 year lifetime represented a reasonable limit. It later set groundwater standards based on concentration limits. Groundwater standards were to be met at any future disposal site for relocated materials, and represented a clean-up standard for sites with contaminated groundwater resulting from the milling process.

Facilities in Germany evolved in a completely different regulatory structure. As a totally government-controlled operation, Wismut operated its facilities according to accepted standards and practices in its own way. This usually meant that doses to workers and the off-site public were maintained below the ICRP limits accepted at the time. In general, restoration practices were typically not employed through 1990. Because of the limited uranium production in West Germany, there were no specific regulations for them, and the re-unification resulted in substantial debate over the regulatory framework to be imposed on the much larger East German uranium industry clean-up.

The German regulatory framework (only recently formalized) for those sites currently beginning restoration employs a risk-based approach. In addition to considering ICRP recommendations for individual dose limits, an optimization procedure is being employed. This evaluates possible reclamation options with respect to the achievable reduction of real risk (individual and collective doses, as well as conventional risks). Risk assessments are based on the current situation using existing land use and population, but also take into account future changes by considering hypothetical (but realistic) exposures as well. The optimization process carried out on this basis takes into account cost aspects and other factors (e.g. community land use plans, public acceptance, requirements for long term institutional control, etc.). By this site specific derivation of restoration requirements, the German Government intends to identify the optimum balance between environmental and economical risks and benefits.

In the U.S., the prescriptive standards allowed the regulator (NRC), the affected states, the DOE (for Title I), and the private owner (for Title II) to agree on what steps were needed to comply with the standards. This process resulted in a "Remedial Action Plan" (RAP). Once agreed to by all parties (prior to restoration beginning), the NRC and States must concur on accomplishments as the identified milestones and deliverables are met. An important element of each RAP has been the identification of how restoration progress and success can be measured. When all actions in the RAP have been completed, remedial action is considered to be finished (because of the previous agreement on the "process"), and the responsibility of the entity performing the restoration ends.

While not as extensive as the abandoned Title I sites in the United States, there are a few smaller mills and a larger number of mining facilities which were abandoned by Wismut in the early days of uranium production, and subsequently became owned by the various communities and some industrial combines. When the re-unification of the two Germanies occurred, the German Government accepted responsibility for restoration of the active Wismut sites which encompass an overall area of about 32 square kilometers. However, the responsibility for remediation of the older sites lies with the owner at the time of re-unification.

An interesting, but loose comparison can be made between the older (abandoned) German facilities and the Wismut facilities with respect to the U.S. Title I and Title II programs. The German "Title I" (old) sites are to be restored by the current owners (in most cases communities) who generally lack both expertise and money. The German "Title II" (industry = Wismut) sites will be remediated with government funds, which are not unlimited, but sufficient to provide effective solutions.

CONTRASTS BETWEEN THE ENVIRONMENTAL RESTORATION CHALLENGES

The most obvious difference between the environmental restoration challenges faced by the US and Germany is the size and scale of individual clean up efforts. While the total volume of tailings and disturbed areas in the two countries is comparable, the number and spread of tailings and mining sites in the U.S. is much greater than in Germany. The size of individual facilities in Germany is therefore much larger. Figure 1 shows a map of Germany with the mining and milling areas of southeastern Germany highlighted. Notice that the density of mining and milling areas within the U.S. was much less than in Germany.

The proximity of very large sources of radon emanation to population centers in Germany has some analogue in the United States. Several U.S. Title I tailings sites were comparably close to nearby populations. These U.S. sites were given the highest priority for remedial action by the DOE and most were relocated (or are in the process of being relocated) to more remote engineered disposal sites. Completed relocated sites included Salt Lake City, UT (2 million m^3), Lakeview, OR (0.7 million m^3), Riverton, WY (1.4 million m^3) and Durango CO (2 million m^3). Title I sites currently being relocated from populated areas include Grand Junction, CO (3.6 million m^3), Gunnison, CO (0.6 million m^3) and Rifle, CO (3.1 million m^3). The authors are unaware of any U.S. Title II sites being relocated as part of their environmental restoration plan.

While radon emanation could be controlled by engineered covers at all of the sites near population centers, the decision to relocate most of these sites to more remote engineered disposal cells was made on the basis of either groundwater contamination or the economics of having to design passive erosion protection which would meet the longevity standard. Most of the relocated sites were along or near major rivers, and the erosion armoring required to demonstrate protection from flooding events expected over the design lifetime was more costly than relocation. At the major Wismut facilities in Germany, the situation is quite different. Groundwater contamination and erosion protection are equally considered in the restoration planning. However, because of the size of the individual sites and the lack of suitable nearby alternative disposal sites in the densely populated area, relocation is not considered viable primarily due to cost. Therefore, the German Government focus is to develop stabilization in place (or at least on-site) designs which provide long-term stability, radon control and groundwater protection.

Currently, the primary human health concern at the Crossen and Seelingstadt mill sites is the inhalation hazard from radon daughter products. A related environmental hazard which has only a limited analogue in the U.S. is the potential geotechnical stability of the German tailings piles. Their size (height above local grade) and their construction methods have resulted in concerns about their stability under potential seismic events. However, recent analyses have demonstrated an adequate margin of safety for conceivable events in the near term. The fine grained nature of the tailings at the two sites (more than 50% of the material is less than 75 microns) and their saturated condition, does make the potential for liquefaction a concern for long term stability. It also makes tailings de-watering more difficult, and Wismut is currently focusing its efforts on developing effective methods. If de-watering can be achieved, stabilization of the two major tailings areas in place may be the most practical approach.

At the Ronneburg site, de-watering the mine workings has prevented significant groundwater contamination up to now. The same is true at the other significant mining sites. As the water is allowed to flow back into the mine workings during the shut-down period, contact with the unmined uranium bearing rock will occur. Due to the substantial changes in underground flow characteristics caused by the mining, this will lead to increased groundwater contamination in comparison to the pre-mining setting. In addition, if the decommissioning plan includes placement of waste rock into the Lichtenberg pit, the oxidation that this material has enjoyed since its removal will contribute to sulfuric acid generation within the resulting groundwater. At the Seelingstadt and Crossen mills, localized groundwater contamination has been identified. The conceptual reclamation of the tailings includes measures to avoid further contaminant release, while the need for aquifer restoration is still under evaluation.

The disturbed surface areas at the two largest mining areas of Ronneburg and near Aue also pose a radon daughter inhalation concern. Even though the waste rock is low grade, the surface area from which radon can emanate is large. Typical Ra-226 levels range from 0.4-2.0 Bq/g (10-50 pCi/g). Therefore, Wismut is developing proposals to consolidate and cover these piles. This is particularly a concern in the area around Aue which is characterized by hills and valleys which tend to trap elevated radon levels over the areas of highest population nearby.

The costs for the environmental restoration actions envisioned in Germany have ranged as high as 13 billion Deutsche Marks (about 8.7 billion U.S. Dollars) for the Wismut facilities alone. These costs include decommissioning of the mine and mill facilities, environmental restoration, and social compensation for the unusually large former Wismut work-force. The costs for restoration of the community and privately held (old) areas, is unavailable. Of course, these costs will greatly depend on the amount of restoration necessary to meet the environmental restoration standards. Currently, the German Government is carrying out a broad radiological survey program to assess the extent of contamination and risk in order to plan any needed restoration.

In contrast, the U.S. Government has spent approximately 900 million dollars through 1992 on restoration efforts at the 24 designated Title I sites, and has commitments to complete (within the next 6 years) the surface restoration work for a total of about 1.4 billion dollars. An additional 600 million dollars is being planned to complete groundwater restoration at the Title I sites. Individual figures spent and being budgeted by private industry for environmental restoration of the Title II mills is unavailable, but it is likely that total costs for Title II will approach those for Title I. This would lead to a total of about 4 billion dollars for all U.S. uranium mill restoration efforts. A direct comparison of costs for U.S. and German programs is difficult because the German program includes many cost components (e.g. decommissioning and social costs) not included in the current U.S. program. In addition, the costs for the U.S. program are spread across a wide distribution of facilities and sites (and do not fully consider abandoned uranium mine restoration) as opposed to the more centralized German program.

CONCLUSIONS

It is concluded that the U.S. Title I and Title II *experience* to date can provide a valuable contribution to the new German program. While the prescriptive U.S. model has succeeded in effective environmental restoration and the removal of possible hazards, the cost has been significant. The use of prescriptive standards, even when few if any nearby populations are currently receiving exposure, guarantees the protection of future generations in the event of loss of institutional control.

The magnitude of the restoration efforts to be carried out in Germany at the few (but very large) Wismut facilities makes reaching agreement on the extent of restoration very important before full scale remediation begins. Considering the magnitude and complexity of their facilities, the German

Government believes that judicious use of site-specific risk based approaches is more appropriate than prescriptive criteria. The application of risk based site specific procedures can guarantee the same degree of protection of human health and the environment as rigorous employment of prescriptive clean-up criteria.

The technical research conducted in the U.S. in the past 10 years during most of the Title I and Title II restoration, can assist in concept development in Germany. Restoration concerns, such as: erosion protection, rock longevity, cover design, vegetation encroachment, the geochemistry of infiltration, long term moisture content, slime de-watering, radon diffusion through soil-like materials, geotechnical stability, and vicinity property clean-up, are being thoroughly reviewed by both Wismut and the German regulatory community. Germany will use these research efforts in developing conceptual restoration plans. The U.S. and German experience together provide a broad background (along with the experience in Canada and Australia, which also have mature uranium mine and mill industries) for the environmental restoration which will be needed around the world in other uranium producing countries.

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