THRESHOLD LIMITS FOR SELENIUM IN THE COAL MINING AREAS OF NEW MEXICO[1]

by

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Abstract: The concerns for selenium (Se) toxicity problems became a major issue to the coal mining industry in the western United States during the 1970's. Problems with Se toxicity in aquatic ecosystems led to a great amount of speculation with regard to Se levels found in backfill and soil materials at surface coal mines. Regulatory agencies quickly established standards to deal with the potential calamity based on limited databases. The standards adopted were very conservative in the context of today's knowledge of the Se toxicity issue. The economic impact of these standards has been substantial as a result of regulatory mitigation requirements. This paper will provide justification supporting the development of less conservative threshold limits for Se in backfill materials at BHP mines located in New Mexico.

Much of the data collected throughout the western United States demonstrates that Se levels corresponding to near maximum threshold limits do not usually result in toxic levels of Se in the vegetation. For example, at the San Juan Mine, New Mexico, the mean hot-water soluble Se for backfill materials was 0.122 ppm. This value is above the suitability limit of 0.10 ppm previously used as the maximum by the New Mexico Mining and Minerals Division. Corresponding levels of Se found in fourwing saltbush were about 0.84 ppm Se. Therefore, near maximum threshold levels of hot-water soluble Se found in the backfill material results in Se levels of fourwing saltbush that are much lower than the 5.0 ppm chronic toxicity level for vegetation. At the Navajo Mine, a study found that cattle grazing reclaimed lands exhibited a deficiency in blood Se levels as opposed to a toxicity. This was the case regardless of the physicochemical quality of root-zone materials. There is clear evidence that chronic Se toxicity to livestock and wildlife is unlikely on grazing rangeland or reclaimed mine lands. There is clear evidence that chronic Se toxicity to livestock and wildlife is only problematic on those sites that provide limited alternatives to high Se vegetation.

Additional Key Words: Se toxicity, blood Se levels, vegetation Se levels, regulatory guidelines, available Se, Se volatilization.

Introduction

The concerns for selenium (Se) toxicity became a major issue with the problems associated with the Kesterson irrigation project in California and the Kendrick Reclamation District project in Wyoming. These findings awakened concerns about the death of livestock and wildlife in the arid west during the 1930's and 1940's that may have resulted from Se toxicity. The fact that coal mine backfill materials inherently contain Se, especially in the carbonaceous shales and marine sediments, sparked some major concerns from regulatory agencies. The presence of Se on coal mine sites became a major issue for operations located in such states as Wyoming, New Mexico, and Arizona. As a result, the regulatory agencies hastily attempted to develop meaningful standards for Se based on the available information to deal with the potential Se calamity. The Se standards adopted by regulatory agencies were very conservative in the context of what is known today about the subject of Se toxicity.

Regulatory standards for Se levels found in soils, overburden, and backfill were established to limit the

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uptake of Se by vegetation that could cause acute and/or chronic toxicities in livestock and wildlife. These standards were based on the best soil/plant correlation data available at the time. Unfortunately, the complexity of the soil chemistry, plant and animal biochemistry, and the interrelationships between these important aspects of Se toxicity chemistry did not allow the development of meaningful correlations between soil available Se and plant uptake and between plant materials and the consumption relationships with the wildlife and domestic animal consumers. Information now available shows that the current regulatory limits for soil Se levels are very conservative. As a result, soil and backfill material Se levels that currently exceed the standards usually do not result in plant Se levels greater than 5 ppm.

Information collected at coal mining operations has greatly reduced the concern that mining and reclamation activities will increase the potential Se toxicity of animals grazing on reclaimed lands. Toxicology studies on wildlife and domestic animals provide evidence that chronic Se toxicity is a concern only on sites that provide limited alternatives to high Se vegetation (Raisbeck et al., 1996). Information indicates livestock and wildlife will not seek nourishment from vegetation containing high Se levels unless these animals are forced to eat such material (Beath, 1920; Heinz and Sanderson, 1990). As a result, chances of toxicity occurring due to the ingestion of plant materials containing high levels of Se will be remote. Toxicity problems with Se have been mostly associated with surface water issues. Such problems have resulted from use of irrigation water heavily laden with Se or other nonpoint or point sources of pollution that have caused significant contamination to surface waters.

Special handling of backfill materials exceeding regulatory standards for Se has resulted in significantly increased mining costs without reciprocal environmental protection. Considering the state of the research on this issue and the economics involved in mitigating potentially suspect backfill materials, a modification to the existing maximum threshold limits for Se at the three BHP Minerals' surface coal mines in northwest New Mexico and other mines located in western United States is warranted.

I. Literature Review Supporting Less Conservative Threshold Limits.

Environmental concerns for Se toxicity have been pushed to the forefront due to the findings of severe toxic impacts to aquatic life at sites such as the Kesterson irrigation project in California (Ohlendorf et al., 1986) and the Kendrick Reclamation District in Wyoming (Ramirez and Armstrong, 1992). Studies on these sites showed that high levels of Se present in water used by the various aquatic organisms might cause serious toxicities. Abnormalities in amphibians and waterfowl hatchlings resulting from entrance of Se into the food chain have been documented at both the Kesterson (Ohlendorf et al., 1986) and the Kendrick (Ramirez and Armstrong, 1992) projects. The dissolution and migration of Se from parent material into surrounding soils and water systems are the primary cause of these environmental disasters. A number of similar documented Se problems have resulted from the dissolution of Se from coal fly ash after being deposited in power plant cooling water lakes (Skorupa, 1998).

Concern for Se problems on arid lands has focused on mine sites located in the western United States where regraded backfill materials inherently contain relatively high concentrations of Se (Fisher and Munshower, 1990; Boone, 1986). The fact that Se is the most highly enriched element found in coal and carbonaceous materials enhanced this concern (Boone, 1986; Valkovic, 1983). Plant uptake of Se has been a major concern in western U.S. coal mines because of its potential toxicity to domestic animals and wildlife. However, recent work completed on mined lands located in Wyoming and New Mexico seems to diminish concerns that mining and reclamation activities will result in Se toxicity on reclaimed areas (Spackman et al., 1995; Vicklund et al., 1995; Gamble, 1997). In addition, there is mounting evidence that other substances may have caused at least some of the so-called Se induced toxicities. O'Toole and Raisbeck (1995) point out that at least in some cases, toxicities attributed to Se were more likely associated with other elements and/or conditions.

The concern for environmental degradation due to Se toxicity on mine sites has resulted in the implementation of special handling programs required by regulatory agencies to keep materials containing high levels of Se out of the plant root zone. The question is, "How much Se can be present in the root zone material without causing environmental degradation or Se toxicity to organisms?" The development of correlations between Se levels in reclaimed soils to plant up-take and to toxicity in animals is required to answer this question.

A number of studies have been done to determine the relationship between extractable Se and total Se levels found in soils and backfill materials and the amount of Se found in plants growing on such sites. These studies, which attempted to correlate total Se levels with plant uptake values, have attained limited success. This is not surprising when considering the chemistry that characterizes Se and the various levels of availability of Se species that might be found in any one environment. In addition, plants have different mechanisms responsible for the transport of various species of Se from soil solution into the plant. The amount of Se that a plant can absorb from a soil solution is dependent on the biochemistry of the plant (Wu, 1998). This is quite obvious, as Se accumulators must have mechanisms that enhance the collection of Se without causing plant toxicity. It is also true that plants have the ability to more readily absorb one species of Se over another. For example, Ulrich and Shrift (1986) showed using Astragalus plants that selenate uptake required energy and selenite uptake appeared energy independent. In addition, levels of selenite in roots never exceeded the solution concentrations; whereas selenate accumulated in the roots. In other words, selenate absorption was done by active transport and selenite uptake was passive. In another study, Wu (1988) found selenate caused greater growth reduction of tall fescue as compared to selenite in tall fescue. In this study, root levels of selenate and selenite were comparable and the levels of selenate were about 4 times higher than selenite in the shoot tissue.

Several studies have demonstrated relationships between soil available (extractable) Se and the amount found in plant materials. Soltanpour and Workman (1980) found that an AB-DTPA extractable Se level of 0.1 mg/kg correlated to the assumed toxic level of Se (>5 mg Se/kg) in alfalfa forage in a greenhouse study using selenate amended Mollisols. This study showed that AB-DTPA solution extracted about 31% more Se from mine and overburden samples compared to hot-water extraction. This information has been used as a basis for many guidance documents currently used by regulatory agencies. Jump and Sabey (1989) found Se extracted from saturated soil pastes was the best predictor of Se in fourwing saltbush and two-grooved milkvetch tissue under greenhouse conditions. Extractable levels of Se generated from AB-DTPA extracts were also found to be highly correlated to the levels found in saturated extracts.

Vicklund et al. (1995) completed a vegetation baseline study at several mines located in the Powder River Basin in Wyoming, comparing Se levels in plants on reclaimed areas with like species located on adjacent undisturbed sites. The results indicated a slight, but distinct, tendency for Se to be greater in like plant species on reclaimed areas as compared to unmined sites. The study also showed that the concentration of Se in vegetation grown on reclaimed areas decreased with time. Geographic location was a very important factor in the amount of Se found in vegetation. This finding may be associated with soil water availability, which has an important role in modifying Se uptake by plants. In a companion study, low soil water content translated to low Se uptake (Spackman et al., 1995). A study associated with the Kendrick Reclamation District showed, plants growing on water-stressed seleniferous soils contained much higher levels of Se as compared to plants grown on the same site one year later when water stress was not an issue (Erdman et al., 1990). These studies appear to contradict one another in regards to moisture availability and plant Se levels.

The study completed by Spackman et al. (1995) was done to develop predictive relationships between Se concentration in the environment and target organisms, and to identify suitability levels for Se in postmining backfill. The vegetation-soil system was found to be very complex and dynamic. Vegetation Se levels were found to decrease from summer to fall. There was an increase in plant Se concentration with depth of the rooting zone material for both unmined and reclaimed sites with unmined sites showing about twice the amount of Se found at the same depth in reclaimed soils. Similar results were reported by Olson et al. (1942) for a seleniferous area located in South Dakota. Spackman et al. (1995) found most sites sampled contained extractable Se levels exceeding regulatory guideline limits of 0.15 mg/kg at depths below 61 cm. However, none of the average Se levels of the plant materials studied exceeded the 5 mg/kg level often cited as hazardous (Palmer, 1985). This finding suggests that mineland reconstruction efforts can be effective in creating a suitable root-zone for reclamation even if some portions of the plant growth material contain levels of Se above regulatory limits.

The amount of Se found in vegetation study was influenced by several soil factors including percent clay, total organic carbon, extractable soil Se, electrical conductivity (EC), sulfates, and the age of the reclaimed site (Spackman et al., 1995). In general, it was not possible to find a direct relationship between vegetation Se and soil extractable Se with the number of samples collected. However, grasses were found to resist Se accumulation and tended to be a good species to use for reclamation of marginal lands containing elevated levels of Se. The overall results of the Wyoming research effort (Vicklund et al., 1995; Spackman et al., 1995) have reduced concerns that mining and reclamation activities in the Powder River Basin of Wyoming will increase potential Se toxicity to animals grazing on upland areas of reclaimed lands.

A major concern for Se toxicity is the uptake of Se by plants followed by deposition and accumulation of Se at the soil surface. The deposition of Se at the surface could enhance the potential of plant uptake and the subsequent toxic impact to biota. Work by Martens and Suarez (1997b) showed that a portion of Se found in shales, alluvial soils, and sediments associated with the Kesterson ecosystem was rapidly mineralized from the selenoamino acids, selenomethionine, and selenocystine to selenate, selenite, elemental Se, selenide, and volatile Se species. Apparently, on many sites much of the Se accumulated in vegetation may be deposited at the surface as a short-lived form. Some of this Se may be lost as vapor during mineralization of organic matter. In addition, some plants have been shown to release Se as a vapor. Banuelos et al. (1995) have shown that various plants such as Indian mustard absorb and volatilize significant amounts of Se on high Se soils. Uptake by such plants and volatilization by microbial populations were responsible for removing about 50% of the soil Se concentrations. Munn (1995) showed Se levels found in native area surface materials did not appear to be related to plant accumulation. This study found evidence suggesting that soil Se content was predominately controlled by geomorphic relationships and by physical and chemical processes (pedogenesis). Although this study did not contemplate volatilization, a portion of the Se losses may have resulted from volatilization losses through vegetation and microbial activity, or by leaching to lower depths in the soil profile following mineralization of organic forms.

Volatile organoselenium species are formed and released into the environment by microbes, plants, and animals (Chasteen, 1998). Se compounds are naturally volatilized into the atmosphere as a result of biological activity in aquatic (Chau et al., 1976) and terrestrial ecosystems (Doran and Alexander, 1977). The volatile compounds identified included dimethyl selenide (DMSe), dimethyl diselenide, dimethylselenone, methane selenol, and hydrogen selenide (Zieve and Peterson, 1981, 1984). DMSe was found to readily sorb to clay and organic matter. Once this compound was sorbed to sites in the soil, microorganisms were responsible for the conversion to other Se forms. Volatilization of Se may be an important mechanism for the removal of selenium from surface soil materials.

Levels of Se in Plant Materials and its Impact on Domestic Animals and Various Forms of Wildlife

Selenium is an essential element in the biological scheme. It is essential in animal and possibly plant metabolisms where deficient levels cause problems. In addition, Se is toxic to animals and plants where it occurs in high concentrations in soils, water, plants, and aerosols. Animals require 0.05 to 0.1 mg Se/kg in their diets to prevent Se deficiency, but may suffer Se toxicosis when dietary levels exceed 5 to 15 mg Se/kg. Chronic toxicity studies have shown diets consisting of 4 to 5 mg Se/kg of body weight can result in chronic toxicity in laboratory animals (NAS-NRC, 1983). The Food and Nutrition Board of the National Academy of Sciences (1980) has accepted 5 mg Se/kg diet as the level between toxic and nontoxic feeds. It is thought by many researchers that economic losses associated with livestock production due to chronic Se toxicities caused by consuming forage with relatively low levels of Se for extended periods of time exceed losses due to acute toxicity (Boone, 1989; Fisher and Munshower, 1990). However, actual research addressing the chronic Se toxicity issue seems to be limited.

As described by O'Toole and Raisbeck (1998), the toxicokinetics of Se are complex and rather poorly understood. The uptake, distribution, metabolism, and elimination of Se by domestic animals and wildlife are impacted by the form of the element, the dosage, the condition of the animal, and interactions with other compounds. Most of the toxicokinetic information collected to date represents information deducted from studies using deficiency diets and diets providing adequate levels of Se for proper metabolic function. Much of the toxicokinetic information is available in more detail in O'Toole and Raisbeck (1998) and other referenced literature and will not be discussed in this paper.

Prolonged oral exposure of cattle to elevated dietary Se in forage and seleniferous plants in seleniferous areas of the United States is associated, historically, with two clinical syndromes: (1) alkali disease and (2) blind staggers (Rosenfeld and Beath, 1964). These researchers highlighted Se as a potential problem element for livestock and wildlife at sites where vegetation uptake of Se resulted in high levels in plant materials. More recently, researchers have described the Se toxicity scare of the 1950's for the northern Great Plains as somewhat of a myth. This popular folklore as described by numerous references to books and articles identified by Raisbeck et al. (1993) may be attributed to other toxic conditions rather than Se toxicity (Raisbeck et al., 1993; O'Tool et al., 1996). However, there has been discussion of recent cases of Se toxicity in horses in southern Idaho consuming high Se forage and water. The primary cause of the Se toxicity symptoms is not readily available. However, previous studies have shown that water can be linked to numerous toxicity issues, while the consumption of high Se vegetation is usually not a primary factor in Se toxicity.

Raisbeck et al. (1995a, 1993) found from their studies of naturally occurring selenosis in Wyoming, that chronic selenosis does occur in domestic animals in the state. Their study did not verify a single case of blind staggers associated with Se toxicity. Recent investigations (O'Toole and Raisbeck, 1995; Raisbeck et al., 1993; Raisbeck, 1992) have determined that the blind staggers condition thought to be associated with Se is more likely due to polioenciphalomalacia, pyrrolizidine, and indolizidine alkaloids; poisoning, malignant catarrhal fever, and starvation, as well as histological misinterpretation of autolysis. Blind staggers does not appear to be a discrete noslological entity and has no proven association with selenosis (O'Toole and Raisbeck, 1995). The symptoms associated with blind staggers are identical to those of polioencephalomalacia, a condition now known to sometimes result from excess dietary sulfur (Raisbeck, 1992).

Raisbeck et al. (1996) found a diet of native grass and alfalfa hay containing 15 ppm dry matter Se did not induce clinically recognizable disease in pronghorn after 164 days of feeding. These researchers believed that either pronghorn may tolerate higher dietary Se than other species, or that Se tissue concentrations are not definitive for diagnosis of selenosis, especially after chronic, low level exposure. The absence of observable disease suggests that the 5 ppm (dry weight) toxic level for dietary Se contents should be modified to include other criteria. These authors suggested that an equally or possibly more-sensitive toxic effect is inhibition of the primary antibody response (PAR) which is a measure of the immune system to respond to an unfamiliar challenge. Unfortunately, this condition may be produced by other toxicants, and therefore, it does not have specificity. However, it is useful if appropriate controls are used.

In a study conducted by Schamber et al. (1995), immunotoxicity of chronic Se exposure was examined using in vitro essays and tests using steers, pronghorn, and mice. This study evaluated toxicity due to selenite, selenocystine, and selenomethionine. The overall results of the study showed increases in dietary Se resulted in impairment of PAR. It was concluded that sodium selenite was found to be the most toxic form of Se studied followed by selenocystine and then selenomethionine. Raisbeck et al. (1996) found that pronghorns fed high Se hay showed significantly less PAR to hen egg albumin (OVA). Although the importance of this observation is uncertain, the most severe potential of this finding is an increase in susceptibility to disease under field conditions. However, it remains to be seen if the deficit observed in their study is high enough to result in an increase in susceptibility.

Raisbeck et al. (1996) noted some interesting observations during their extensive Se studies, "Our initial impression of the 5 ppm "magic number," based on 3 years of field observations, was that it was excessively conservative." Forage for domestic and wildlife species with more than 5 mg Se/kg of dry tissue is considered capable of producing chronic toxicities if provided for sustained consumption (National Research Council, 1976). The interpretation of this "toxic level" often is erroneously described as the presence of any vegetation greater than 5 ppm Se renders a whole pasture hazardous. As noted previously, Se concentrations of 0.05 to 0.1 mg Se/kg diet and 5 to 15 mg Se/kg diet may be considered as critical levels of adequacy and toxicity, respectively. These values are based on total dietary intake. For a feed source to cause chronic toxicity, these criteria require that the entire intake must contain Se levels in the 5 to 15 mg/kg range dependent on species and other factors. Raisbeck et al. (1996) noted that seleniferous vegetation has to be widely and fairly uniformly distributed to pose much of a hazard to well managed cattle (antelope seem to be more selective). In addition, these researchers noted that pasture evaluations should focus on non-accumulator plant species, or (preferably) biomonitors such as grazing animals, which integrate all of the variables involved in Se bioavailability. The conclusions of this work were that: 1) none of the experiments or field studies undertaken since 1989 have been able to convincingly link chronic selenosis in ruminants to forage Se concentrations less than 5-10 ppm; and 2) many of the animals that were studied have apparently tolerated this same range of Se levels.

The work accomplished by Raisbeck et al. (1996) seems to show that chronic toxicity impacts of Se on grazing animals are limited where animals are not forced to eat vegetation that contains high levels of Se. In fact, as noted by Beath (1920) "when cattle were placed in enclosures on Astragalus they would not touch the plant at all and after a few days could not be kept inside the fence." Studies show that cattle, pronghorn, and other animals tend to discriminate against using plants containing high levels of Se. Heinz and Sanderson (1990) found similar results for mallards. In their study, adult mallards were given a choice between a control diet and a diet containing 5, 10, or 20 ppm Se as selenomethionine dissolved in water and mixed into the diet. The food containing 10 and 20 ppm Se was avoided. The avoidance appeared to be caused by a conditioned response, probably to illness caused by the Se and not to an aversion to the taste of the Se.

An important consideration in Se toxicity is related to animal populations that have very limited home ranges. These populations may be impacted to a greater extent than domestic and wildlife species that have larger feeding ranges. With this in mind, Raisbeck et al. (1995b) studied deer mice populations on several mine sites located in Wyoming to determine if mice located on reclaimed lands contained differing levels of Se compared to unmined areas. They found that deer mice living on reclaimed sites had livers that contained higher levels of Se than those living on unmined sites. With the limited amount of information available, these researchers were not able to definitively determine the health effects of elevated Se levels on deer mice. However, the deer mice that had higher levels of Se in their livers also were heavier. This conclusion may show that Se was present in deficient levels on unmined sites resulting in low body weight for deer mice populations. The researchers indicated that additional work would be needed before this conclusion could be substantiated.

II. Soil And Vegetation Data Collected From The Southwestern Coal-mining Region Supporting Environmentally Acceptable Threshold Limits.

Several studies conducted over the past 15 years have provided strong evidence that Se toxicity is not a concern for domestic livestock or wildlife grazing on most reclaimed coal-mined lands in southwestern states. The following is a general discussion of Se related studies conducted in the southwestern mining region.

Site-specific Se standards for the Peabody Western Coal Company Black Mesa Mine Complex, Arizona – 1998.

Peabody Western Coal Company (PWCC) conducted a number of studies at their Black Mesa Mine Complex (BMMC) evaluating soils, plants, and animals relative to the impacts of Se (PWCC unpublished submission to OSM, 1998). BMMC is located in the 4-corners region of Arizona, about 20 miles south of Kayenta. As a result of these studies, a report was developed to justify a change in the established Office of Surface Mining (OSM), Maximum Threshold Limits (MTL) for total and soluble Se. The modified Se standards were considered more appropriate for determining physiochemical suitability of the reclaimed root-zone at BMMC.

Se levels in soil, overburden, and regraded backfill materials were established from analysis of samples collected in various studies and from routine regraded backfill sampling. Peabody concluded that Se characteristics and relationships for soil, overburden, and backfill at the BMMC compared closely with regional data from the western United States. In addition, PWCC conducted forage evaluations for several reclaimed sites during 1995 and 1996. Studies showed that Se found in forage collected from reclaimed areas was comparable with Se levels from forage collected on unmined areas at the site and with values reported in the literature. In addition, it was found that total Se levels of 1.5 mg/kg or less in either soil or backfill materials did not result in Se levels in grasses and shrubs greater than 5.0 mg/kg. These data clearly suggested that the OSM, Root-Zone Suitability Standards for Southwestern United States of 0.8 mg/kg total Se for soil and backfill materials is conservative. Statistical evaluations were also conducted by PWCC to determine if predictive relationships could be derived from the data. A regression analysis indicated that Se levels in soil and backfill material would have to increase substantially above the established Se MTL to have plant Se levels greater than the 5.0 mg/kg.

A livestock study was also conducted by Peabody, University of California-Davis, University of Arizona, and the Navajo Nation during the 1996 grazing season. Health and whole blood Se levels of the cattle were monitored. The research found no evidence of Se toxicosis in any of the cattle, which had averaged whole blood Se levels of 0.2 ppm. This level is slightly above the recommended minimum of 0.1 ppm at which deficiency symptoms begin to occur and is well below the chronic toxicity threshold of 2.0 ppm (Palmer 1985)

Based on the results of these studies and from statistical evaluations of plant soil/backfill relationships, OSM approved a change in 1998 to the MTL's for graded backfill materials at the BMMC from 0.8 to 2.5 mg/kg for total Se and from 0.15 to 0.26 mg/kg for hot-water soluble Se, and from 0.15 to 0.31 mg/kg for AB-DTPA extractable Se. Peabody considers these values to be very conservative because the MTL's are based on upper confidence interval limits. In addition, the MTL's were determined using Se uptake by shrubs (secondary Se accumulators) and do not account for the replaced soil cover which contains very low levels of Se.

Reclamation Materials Suitability Assessment – Burnham Mine, New Mexico

The Burnham Mine is located in northwestern New Mexico approximately 15 miles south of the Navajo Mine. An assessment of the suitability of reclamation materials found at the Burnham Mine was conducted by Munk (1996). This report indicated that much of the Se found in backfill materials at the Burnham Mine is associated with the recalcitrant organic and selenide mineral forms. Release of these forms of Se was expected to be slow because the arid conditions at the mine site are not conducive to microbial activity and to chemical weathering processes. Se released from these pools into an alkaline environment may be oxidized and leached to lower depths in the profile, precipitated as solid state gypsum or carbonate minerals, or absorbed by plants and incorporated into their tissue.

This evaluation was developed to justify the position against mitigating backfill materials that exceeded the 0.80 mg/kg total Se MTL specified in the regulatory guideline. Risks associated with Se at Burnham Mine were small based on low levels of soluble Se, low adsorbed and carbonate related Se, and on the AB-DTPA extractable Se levels. Plant available Se concentrations were not predicted to increase significantly in the future since weathering and microbial degradation are climatically limited and dissolution of solid state gypsum was also believed to contribute Se, but at a slow rate. Based on field observations, climatic conditions, and solution chemistry, gypsum is expected to be rather stable and persist at Burnham Mine. Therefore, the soluble Se levels are predicted to remain relatively constant as backfill materials weather. The report was used to justify a total Se of 2.1 mg/kg for the secondary root-zone (below 6 inches) at the Burnham Mine. OSM approved this request.

Selenium Studies Conducted at the BHP Minerals Navajo Mine (NJM), New Mexico and San Juan Mine (SJM), New Mexico in 1985.

A study was conducted at NJM and SJM by Dr. Ivan Palmer (1985) to examine the Se content of fourwing saltbush (Atriplex canescens) growing on unmitigated, reclaimed mine backfills and on native, undisturbed areas. Plant tissue was collected from ten reclaimed backfill sites and 12 undisturbed sites at Navajo Mine, and from 12 reclaimed backfill sites and 12 undisturbed sites at San Juan Mine. Means, standard deviations, and ranges were determined for total and hot-water soluble Se levels in backfill and soil samples, and for Se levels of vegetation on soil and backfill areas. The Se levels for plant materials and their corresponding levels of Se found in soil and backfill materials are shown in Table 1. The conclusion of this study was that secondary Se accumulator plants growing on unmitigated, reclaimed backfills contained similar levels of Se to those growing on undisturbed soils. In addition, Se levels found in backfill materials at both mines, which often exceeded threshold limits, did not result in fourwing saltbush that exceeded the 5.0 mg/kg chronic toxicity level.

Table 1. Se values for soil and backfill materials and corresponding plant materials tested at the Navajo and San Juan Mines.

Mine/Matrix	Total Se (mg/kg)			Hot-water soluble Se (mg/kg)		
	Mean	SD	Range	Mean	SD	Range
Navajo Mine						
backfill	0.48	0.19	0.24-1.16	0.055	0.043	0.01-0.16
Soil	0.14	0.11	0.07-0.46	0.012	0.004	0.01-0.02
fourwing saltbush – backfill	1.22	0.93	0.30-3.56			
fourwing saltbush - soil	0.95	1.11	0.28-5.70			
San Juan Mine						
backfill	0.43	0.14	0.19-0.76	0.122	0.052	0.006-0.22
Soil	0.19	0.06	0.11-0.28	0.007	0.003	0.003-0.01
fourwing saltbush – backfill	0.84	0.34	0.48-1.56			
fourwing saltbush - soil	0.83	0.37	0.31-1.72			

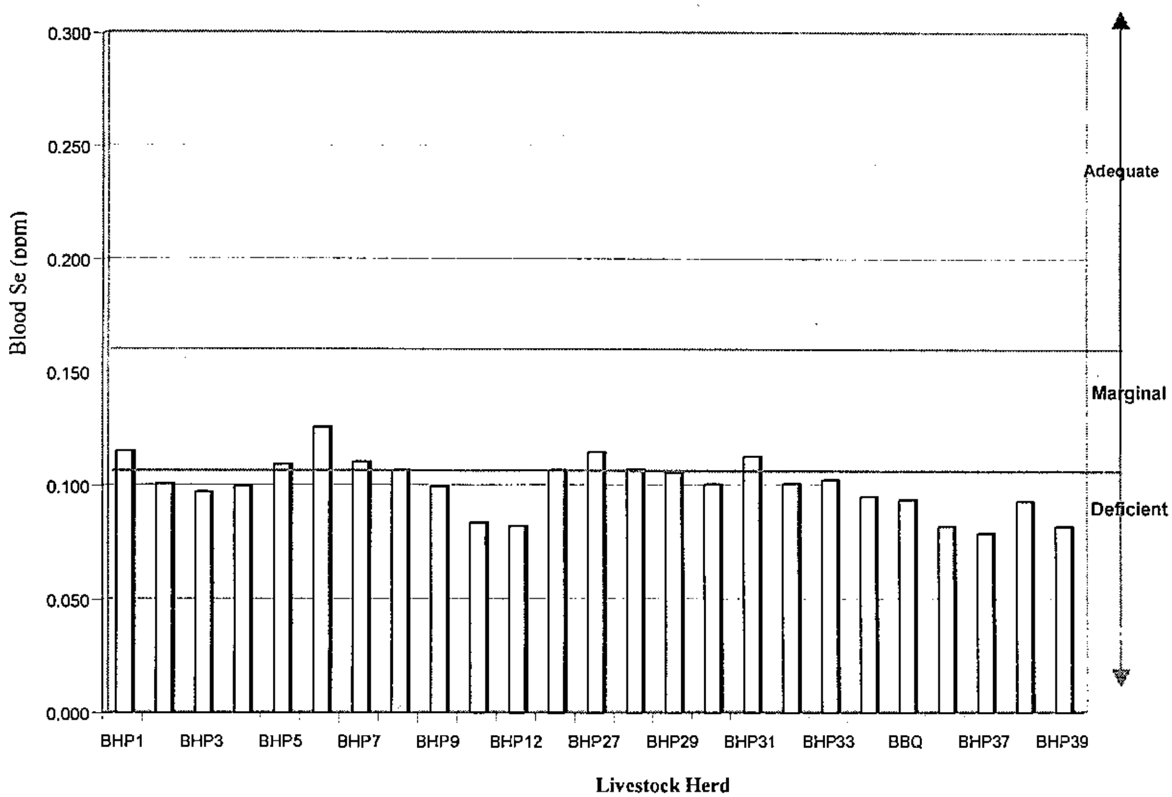
III. Livestock Grazing Study at Navajo Mine, New Mexico

A livestock grazing study was conducted at the Navajo Mine by Gamble et al. (1997) to determine blood Se levels in cattle grazing reclaimed lands. In this study, cattle were used as biomonitors to determine the potential Se hazard associated with areas reclaimed under divergent reclamation performance standards.

The reconstructed root-zone on reclaimed areas used in this study consisted of regraded backfill material covered with a thin layer of respread topsoil ranging from 6 to 12 inches of thickness. Areas grazed were reclaimed before (pre-law) and after (post-law) the promulgation of the Surface Mining Control and Reclamation Act of 1977. Root-zone suitability was not considered during the reclamation of the pre-law areas. Therefore, some of the regraded backfill materials exceeded the MTL for total and soluble Se established by OSM. Although suspect backfill materials were not mitigated in pre-law areas, backfill sampling and analysis were conducted in a large portion of the pre-law areas grazed. The results of analysis revealed that backfill materials ranged from 0 to 6.25 mg/kg for total Se and 0 to 0.9 mg/kg for hot-water soluble Se. Post-law areas were characterized in terms of backfill suitability and appropriately mitigated to achieve a 4-foot viable root-zone. Consequently, surficial root-zone materials in post-law areas were within the OSM MTL for the Navajo Mine of 0.15 mg/kg and 0.80 mg/kg for soluble and total Se, respectively.

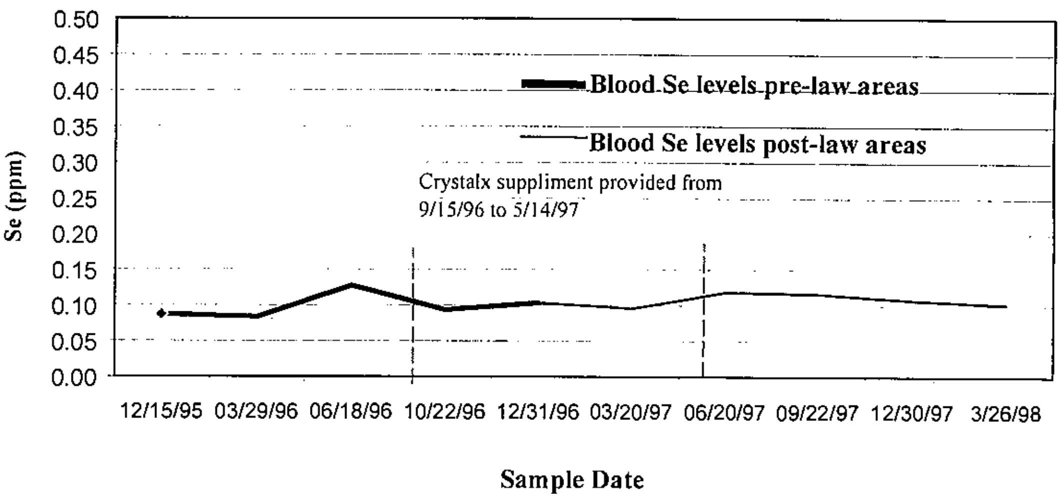
Results of the blood Se concentrations collected on a quarterly basis averaged over the period from December 1995 through March 1998 are provided in Figure 1. Cattle grazed from December 1995 through March 1997 on pre-law reclamation areas. On March 27, 1997, the animals were transferred to post-law reclamation areas. The mean blood Se levels from animals grazing on the pre-law areas was similar to the blood Se levels measured from animals grazing on post-law areas. Overall average levels of Se found in the blood for both of the grazed areas were in the deficient to marginal range. As shown in Figure 2, animals were experiencing the same exposure to Se deficiency whether using pre-law or post-law reclaimed lands. This information appears to indicate that ungulates can graze unmitigated, reclaimed areas that have characteristically variable levels of Se without experiencing any toxicity symptoms. In fact, the major concern appears to be related to Se deficiency problems of livestock and wildlife grazing these reclaimed areas. This is further supported by the fact that the herd was given the nutrient supplement CrystalX containing 4.4 ppm of Se during the period of September 15, 1996 through May 14 1997. The supplement was provided to the animals on a volunteer basis. The data in Figure 2 show near deficient blood Se levels during the supplement period. An unexplained reduction in blood Se levels was also observed during this period.

Figure 1. Blood Selenium Levels for Livestock Herds Grazed on Reclaimed Areas at Navajo Mine, New Mexico†



† Average Se Values Based on Quarterly samplings taken Dec. 1995 through Mar.1998

Figure 2. Average Blood Selenium Levels (ppm) for Livestock Grazed On Reclaimed Areas at Navajo Mine



Information collected during this study, shows that unmitigated backfill materials at the Navajo Mine apparently do not pose potential Se toxicity risks for livestock. Since the geology and climate of the study area closely resembles other mines in the general area, similar results would be expected at such operations. Therefore, reclaimed sites that contain marginal Se levels (as determined using current guideline threshold limits) would not be expected to result in chronic Se toxicity problems in livestock.

Conclusion

Selenium can be a toxic element responsible for severe problems associated with wildlife and livestock. Various species of aquatic wildlife, which are in immediate contact with Se, may often show affects of Se toxicity (i.e., Kesterson Irrigation Project). However, according to the literature, there is clear evidence that chronic Se toxicity to livestock and wildlife is unlikely on grazing rangeland or reclaimed mine lands. The literature provides a strong indication that Se toxicity will not be an issue if vegetation containing high levels of Se does not dominate the food source. Research indicates that livestock and wildlife will not seek nourishment from vegetation containing relatively high levels of Se unless it is the only food source. In addition, work by Reisbeck and his associates (1996) has shown that the entire diet of a ruminant animal would need to contain an average of 5 ppm Se to cause Se toxicity. These researchers indicated that the 5 ppm chronic toxicity limit was excessively conservative. It is highly unlikely that this situation even exists on reclaimed lands in the southwestern United States. The recent research efforts on soil Se/plant uptake relationships have reduced the concern that mining and reclamation activities will increase potential Se toxicity of animals grazing on reclaimed lands.

Selenium levels found in reclaimed areas within New Mexico indicate that mining and reclamation activities pose little risk to livestock using such areas. This is based on the findings of numerous research efforts conducted in the coal mining regions of New Mexico, Wyoming, and throughout the country. In addition, mining companies located in the coal-mining region of New Mexico and Arizona have demonstrated that soil and backfill Se levels on the average do not exceed the current MTL's used by OSM or New Mexico Mining and Minerals Division. Overall, four major conclusions emerge from the studies described in this paper: (1) the majority of the Se values associated with the soil, backfill, and overburden data does not exceed any MTL's used by State and Federal Regulatory Agencies; (2) the majority of the Se values associated with plant materials, including secondary Se accumulators, do not exceed the 5.0 ppm level usually used as a chronic toxicity limit; (3) soil and backfill materials containing levels of Se exceeding the MTL's usually do not result in native grasses and shrubs, including secondary accumulators, that contain Se levels near the 5.0 ppm chronic toxicity limit; and (4) domestic livestock that consume vegetation growing on unmitigated reclaimed sites, which characteristically consist of materials that exceed the MTL's for Se (regulatory standards), do not contain blood Se levels above normal.

Literature Cited

Banuelos, G. S., N. Terry, A. M. Zayed, and L. L. Wu. 1995. Managing high soil selenium with phytoremediation. Pp. 394-405. In Gerald E. Schuman and George F. Vance (eds.) Special Symposium on Selenium: Mining, Reclamation, and Environmental Impacts. 1995 National Meeting of the American Society for Surface Mining and Reclamation. June 3-8, 1995. Gillette, WY.
https://doi.org/10.21000/JASMR95010394

Beath, O. A. 1920. Chemical examination of Astragalus bisulcatus. University of Wyoming, Agricultural Experiment Station 31st annual report, p. 127.

Boone, David Y. 1986. Potential selenium problems in Great Plains soils. Pp. 107-121. In L. W. Jacobs (ed.) Selenium in Agriculture and the Environment. Soil Sci Soc. Am. Spec. Pub. No. 23. 233 p.

Chasteen, Thomas G. 1998. Volatile chemical species of selenium. . In William T. Frankenberger, Jr. and Richard A. Engberg (eds.), Environmental Chemistry of Selenium. Pp. 589-612. Marcel Dekker, Inc. New York.

Chau, Y. K., P. T. S. Wong, B. A. Silverberg, P. L. Luxon, and G. A. Bengert. 1976. Methylation of selenium in the aquatic environment. Science 912:1130-1131.
https://doi.org/10.1126/science.192.4244.1130

Doran, J. W., and M. Alexander. 1977. Microbial formation of volatile selenium compounds in soil. Soil Sci. Soc. Am. J. 41:70-73.
https://doi.org/10.2136/sssaj1977.03615995004100010022x

Erdman, J. A., R. C. Severson, J. G. Crock, T. F. Harms, and H. F. Mayland. 1990. Selenium in soils and plants from native and irrigated lands at the Kendrick Reclamation Project Area, Wyoming. Pp. 91-105. In Proceedings of the 1990 Billings Land Reclamation Symposium on Selenium in Arid and Semi-arid Environments, Western United States. March 25-30, 1990, Billings, MT. U. S. Geological Survey Circular 1064. 146 p.

Fisher, Jr., Scott E., and Frank F. Munshower. 1990. Selenium issues in drastically disturbed land reclamation planning in arid and semi-arid environments. Pp. 125-133. In Proceedings of the 1990 Billings Land Reclamation Symposium on Selenium in Arid and Semi-arid Environments, Western United States. March 25-30, 1990, Billings, MT. U. S. Geological Survey Circular 1064. 146 p.

Gamble, Dean C., Kirk L, Gadzia, and Merl F. Raisbeck. 1997. Livestock grazing for management of reclaimed land at Navajo Mine: Animal response. p. 255-261. In Jon E. Brandt (ed.) Proceedings of 1997 National Meeting of the American Society for Surface Mining and Reclamation. May 10-15, 1997. Austin, Texas.
https://doi.org/10.21000/JASMR97010255

Heinz, G. H., and C. J. Sanderson. 1990. Avoidance of selenium-treated food by mallards. Environ. Toxicol. Chem. 9:1155-1158.
https://doi.org/10.1002/etc.5620090906

Jump, R. K., and B. R. Sabey. 1989. Soil test extractants for predicting selenium in plants. Pp. 95-105. In L. W. Jacobs (ed.), Selenium in Agriculture and the Environment, Special Publication 23. Soil Science Society of America, Madison, WI.

Martens, D. A., and D. L. Suarez. 1997b. Selenium speciation of soil/sediment determined with sequential extractions and hydride generation atomic absorption spectrophotometry. Environ. Sci. Technol. 31:171-177.
https://doi.org/10.1021/es960214+

Munk, Lewis. 1996. Reclamation materials suitability assessment – Burnham Mine San Juan County, New Mexico. Report Prepared for Consolidation Coal Company. 32p.

Munn, Larry C. 1995. Factors controlling distribution of selenium by geomorphic and pedologic processes in a semi-arid environment, Laramie Basin, Wyoming. Pp. 270-283. In Gerald E. Schuman and George F. Vance (eds.). Special Symposium on Selenium: Mining, Reclamation, and Environmental Impacts. 1995 National Meeting of the American Society for Surface Mining and Reclamation. June 3-8, 1995. Gillette, WY.
https://doi.org/10.21000/JASMR95010270

National Academy of Science – National Research Council. 1983. Selenium in Nutrition. NAS-NRC. Washington, D. C.

National Research Council. 1976. Selenium. Assembly of Life Sciences, Committee on Medical and Biological Effects of Environmental

Pollutants, National Academy of Sciences. Washington, D. C. 203 p.

Ohlendorf, H. M., D. J. Hoffman, M. K. Saiki, and T. W. Aldrich. 1986. Embryonic mortality and abnormalities of aquatic birds—Apparent impacts of selenium from irrigation drainwater. Sci. Total Environ. 52:49-63.
https://doi.org/10.1016/0048-9697(86)90104-X

Olson, O. E., E. I. Whitehead, and A. L. Moxon. 1942. Occurrence of soluble selenium in soil and its availability to plants. Soil Sci. 54:47-53.
https://doi.org/10.1097/00010694-194207000-00004

O'Tool, Donal, and Merl F. Raisbeck. 1995. Pathology of experimentally induced chronic selenosis (alkali disease) in yearling cattle. J. Vet. Diagn. Invest. 7:364-373.
https://doi.org/10.1177/104063879500700312

O'Tool, D., M. F. Raisbeck. J. C. Case, and T. D. Whitson. 1996. Selenium-induced blind staggers and related myths. A commentary on the extent of historical livestock losses attributed to selenosis on western U. S. rangelands. Vet. Pathol. 33:104-116.
https://doi.org/10.1177/030098589603300117

O'Toole, D., and M. F. Raisbeck. 1998. Magic numbers, elusive lesions: Comparative pathology and toxicology of selenosis in waterfowl and mammalian species. In William T. Frankenberger, Jr. and Richard A. Engberg (eds.), Environmental Chemistry of Selenium. Pp. 355-395. Marcel Dekker, Inc. New York.

Palmer, Ivan. 1985. Data Report Prepared for BHP Minerals.

Peabody Western Coal Company. 1998. Report submitted to OSM-WRTL, Denver, CO.

Raisbeck, M. F. 1992. Is polioencephalomalacia associated with high-sulfate diets? J. Amer. Vet. Med. Assoc. 180:1303-1305.

Raisbeck, M. F., E. R. Dahl, D. A. Sanchez, E. L. Belden, and D. O'Toole. 1993. Naturally occurring selenosis in Wyoming. J. Vet. Daign. Invest. 5:84-87.

Raisbeck, M. F., D. O'Toole, D. A. Sanchez, R. A. Siemion, and Waggoner. 1995a. O'Tool, Donal, and Merl F. Raisbeck. 1995. Pathology of experimentally induced chronic selenosis (alkali disease) in yearling cattle. J. Vet. Diagn. Invest. 7:364-373.
https://doi.org/10.1177/104063879500700312

Raisbeck, Merl L., D. G. Mickey Steward, Laurel E. Vicklund, George F. Vance, Lowell K. Spackman, and James G. Luther. 1995b. Selenium and mining in the Powder River Basin, Wyoming: Phase III – A preliminary survey of selenium concentrations in deer mice (Peromyscus maniculatus) livers. Pp. 354-361. In George F. Vance and Gerald E. Schuman (eds.). Special Symposium on Selenium: Mining, Reclamation, and Environmental Impacts. 1995 National Meeting of the American Society for Surface Mining and Reclamation. June 3-8, 1995. Gillette, WY.
https://doi.org/10.21000/JASMR95010354

Raisbeck, M. F., D. O'Toole, R. Al Schamber, E. L. Belden, and L. J. Robinson. 1996. Toxicologic evaluation of a high-selenium hay diet in captive pronghorn antelope (Antilocapra americana). J. Wildlife Diseases 32(1):9-16.
https://doi.org/10.7589/0090-3558-32.1.9

Ramirez, P., and J. A. Armstong. 1982. Biota. In Detailed Study of Selenium in Soil, Representative Plants, Water, Bottom Sediment, and Biota in the Kendrick Reclamation Project Area, Wyoming 1988-1990, pp. 69-114. U. S. Geological Survey, Water Resources Invest. Report No. 91-4131. USGS, Cheyenne.

Rosenfeld, I., and O. A. Beath. 1964. Selenium geobotany, biochemistry, toxicity, and nutrition. Pp. 141-213. Academic Press. New York, N.Y.

Schamber, Robin A., E. Lee Belden, and Merl F. Raisbeck. 1995. Pp. 384-393. In Gerald E. Schuman and George F. Vance (eds.). Special Symposium on Selenium: Mining, Reclamation, and Environmental Impacts. 1995 National Meeting of the American Society for Surface Mining and Reclamation. June 3-8, 1995. Gillette, WY.
https://doi.org/10.21000/JASMR95010384

Skorupa, Joseph P. 1998. Selenium poisoning of fish and wildlife in nature: Lessons from twelve real-world examples. In William T. Frankenberger, Jr. and Richard A. Engberg (eds.), Environmental Chemistry of Selenium. Pp. 315-354. Marcel Dekker, Inc. New York.

Soltanpour, P., and S. Workman. 1980. Use of NH_4HCO_3-DTPA soil test to assess availability and toxicity of selenium to alfalfa plants. Comm. Soil Sci. and Plant Anal. 11:1147-1156.
https://doi.org/10.1080/00103628009367111

Spackman, Lowell K., D. G. Mickey Steward, Laurel E. Vicklund, George F. Vance, and James G. Luther. 1995. Pp. 333-353. In Gerald E. Schuman and George F. Vance (eds.). Special Symposium on Selenium: Mining, Reclamation,

and Environmental Impacts. 1995 National Meeting of the American Society for Surface Mining and Reclamation. June 3-8, 1995. Gillette, WY.
https://doi.org/10.21000/JASMR95010333

Ulrich, J. M., and A. Swift. 1986. Selenium absorption by excised *Astragalus* roots. Plant Physiol. 43:14-20.
https://doi.org/10.1104/pp.43.1.14

Valkovic, F. 1983. Trace Elements in Coal. CRC Press, Boca Raton, FL.

Vicklund, Laurel E., George F. Vance, D. G. Mickey Steward, Lowell K. Spackman, and James G. Luther. 1995. Pp. 317-331. In Gerald E. Schuman and George F. Vance (eds.). Special Symposium on Selenium: Mining, Reclamation, and Environmental Impacts. 1995 National Meeting of the American Society for Surface Mining and Reclamation. June 3-8, 1995. Gillette, WY.
https://doi.org/10.21000/JASMR95010317

Wu, L., Z. Z. Huang, and G. R. Burau. 1988. Selenium accumulation and selenium-salt cotolerance in five grass species. Crop Sci. 28:517-522.
https://doi.org/10.2135/cropsci1988.0011183X002800030019x

Wu, Lin L. 1998. Selenium accumulation and uptake by crop and grassland plant species. In William T. Frankenberger, Jr. and Richard A. Engberg (eds.), Environmental Chemistry of Selenium, pp. 657-686. Marcel Dekker, Inc. New York.

Zieve, R., and P. J. Peterson. 1981. Factors influencing the volatilization of selenium from soil. Sci Total Environ. 19:277-284.
https://doi.org/10.1016/0048-9697(81)90022-X

Zieve, R., and P. J. Peterson. 1984. The accumulation and assimilation of dimethyl selenide by four plant species. Planta 160:180-184.