Cleaning up the Streets of Denver

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ABSTRACT

Between 1913 and 1924, several Denver area facilities extracted radium from carnotite ore mined from the Paradox basin region of Colorado. Tailings or abandoned ores from these facilities were apparently incorporated into asphalt used to pave approximately 7.2 kilometers (4.5 miles) of streets in Denver. A majority of the streets are located in residential areas. The radionuclides are bound within the asphalt matrix and pose minimal risk unless they are disturbed. The City and County of Denver (CCoD) is responsible for controlling repairs and maintenance on these impacted streets. Since 2002, the CCoD has embarked on a significant capital improvement project to remove the impacted asphalt for secure disposal followed by street reconstruction. To date, Parsons has removed approximately 55 percent of the impacted asphalt. This paper discusses the history of the Denver Radium Streets and summarizes on-going project efforts.

INTRODUCTION

The discovery of radium by Marie Curie in 1898 provided scientists an element with radioactive and luminescent properties never before encountered. Pierre Curie's pioneering work on the biological affects of radiation led to the first commercial use of radium for the treatment of cancer and other ailments. Radium's miraculous ability to cure cancer was widely publicized in the press and created a demand for consumer health products containing radium. Luminescent watch and clock faces also became immensely popular. Europe dominated the radium market until 1911 when the Standard Chemical Company began extracting radium from Colorado carnotite ore at facilities located near Pittsburgh, Pennsylvania [1].

Because of the significant strategic value of radium and the continued instability of Europe leading into World War I, the National Radium Institute with funding from the U.S. Bureau of Mines set out to develop a cost-effective extraction process to bolster domestic production of radium from Colorado carnotite ores. The National Radium Institute operated an experimental extraction plant in Denver between 1913 and 1917. The plant was able to successfully extract 8.5 grams of radium at an average cost of $38,000 per gram, about one-third the world price [2].

With demand for radium products increasing, abundant quantities of carnotite ore located in the Paradox basin region of Colorado, and a new economical process to process the ore, several companies established radium extraction operations in the Denver area. These facilities produced a significant portion of the radium used in the United States between 1917 and 1922. The demise of the Denver radium industry is linked to the exploration of higher-grade Belgian Congo ores in 1922. The Belgian Congo ores contained up to 50 percent uranium oxide compared to 2 percent for the average Colorado carnotite. With falling world prices for radium, radium extraction from carnotite became uneconomical. By 1924, almost all of the Denver area extraction facilities were closed or converted to process other minerals [1].

IMPACTED STREET DISCOVERY

In 1979, the United States Environmental Protection Agency (EPA) encountered a reference to the National Radium Institute in a 1916 U.S. Bureau of Mines report [3] and launched an investigation to determine if radioactive contamination was present at these locations. During the investigation, elevated gamma radiation fields along nine street segments were unexpectedly detected. The EPA added the street segments to the National Priorities List (NPL or superfund list) in 1983. Fig. 1 shows the locations of the nine street segments, which extend approximately 7.2 kilometers (4.5 miles) primarily through residential neighborhoods. An estimated 800 homes are adjacent to these impacted streets.

Fig. 1. Location of Denver Radium streets

In 1982, ARIX was contracted by the State of Colorado to characterize the radioactivity associated with the impacted streets [4]. The typical gamma radiation field ranged from 0.3 to 0.6 microSieverts per hour (µSv/hr) [30 to 60 microRoentgens per hour (µR/hr)] at a distance of 1 meter directly above the pavement surface[1]. The radiation field dropped off to background levels [approximately 0.2 µSv/hr (20 µR/hr)] along the adjacent non-paved right-of-way. Samples of the asphalt were also collected and analyzed. The radium concentration results ranged from 150 to 2,900 becquerels per kilogram (Bq/kg) [4 to 79 picocuries per gram (pCi/g)]. Residual contamination was not detected in the soils immediately below the impacted asphalt. Although the asphalt pavement thickness ranged from 18 to 25 centimeters (7 to 10 inches), the radioactivity was detected only in the lower portions of the pavement suggesting that the original impacted asphalt pavement was covered by subsequent paving operations.

Samples of impacted asphalt were collected in 2004 for isotopic analyses to provide additional characterization information for transportation and disposal. Ten samples were collected and analyzed using a combination of alpha and gamma spectroscopy. The Ra-226 activity ranged from approximately 330 to 4,800 Bq/kg (9 to 130 pCi/g). The total radioactivity of the impacted asphalt ranged from 5,500 to 48,000 Bq/kg (150 to 1300 pCi/g) with Th-230, Ac-227, Ra-226, and U-234 accounting 95 percent of the activity.

It is postulated that the elevated readings are a result of incorporating tailings or excess carnotite ores in the asphalt mix used to pave these streets. The radioactive components primarily consist of natural radium, thorium, uranium, and associated daughter products including radon gas. These radioactive materials can pose a threat to human health and the environment though potential exposure pathways including, but not limited to, inhalation, ingestion, and direct contact. However, with the radioactive materials bound in the asphalt matrix and shielded by the non-impacted asphalt overlays, the EPA concluded that the impacted asphalt posed a minimal risk to public health in its present state unless disturbed by street maintenance or utility work [3]. In 1986, EPA adopted a Record of Decision (ROD) for the Denver Radium Streets to allow the impacted asphalt to remain in place as long as institution controls to monitor street disturbance were implemented. Should impacted asphalt removal be required, the cleanup standards for inactive uranium sites specified in Code of Federal Regulations, Title 40, Part 192, were mandated in the ROD. The EPA concluded that, with the proper administrative and technical controls, any disruption of the impacted asphalt, including complete reconstruction of the street, would pose minimal risk to workers or the public. This ROD was amended in 1992 to allow placement of impacted asphalt back into a street repair excavation if the disturbance was less than 20 percent of the total roadway area in one city block [5].

IMPACTED ASPHALT REMOVAL

The CCoD has controlled, coordinated, and monitored street maintenance activities since 1989 [6]. With aging streets that are no longer cost-effective to resurface and maintain, an alternate

[1] During removal of the impacted asphalt, waist level gamma fields up to 1.4 µSv/hr (140 µR/hr) have been measured.

approach to the management controls was required. In 2002, the CCoD embarked on a long-term program to remove the impacted asphalt followed by street reconstruction. After a street is reconstructed, management controls are no longer required making future street maintenance less costly.

Parsons has been retained by CCoD since 2003 to manage and execute the impacted asphalt removal and reconstruction activities. The estimated completion date for the street reconstruction program is 2007. To date, more than 15,600 tonnes (17,200 tons) of radium-impacted asphalt have been removed. The completed street segments are identified on Fig. 1 and represent approximately 55 percent of the total impacted area.

The project scope is being executed in discrete packages on an annual basis. For each discrete package, the work was planned and sequenced to control access and safely perform activities. After the phasing plan was established, a detailed schedule was prepared and the required permits obtained. Potential utility interferences were identified and coordinated with the utility owner to provide the necessary adjustments.

Prior to impacted asphalt removal, construction fencing was erected around the work area to preclude public exposure to impacted materials. Site security personnel were present at the project site 24 hours per day, 7 days per week to monitor and mitigate unauthorized access into the work area. Traffic control devices and signs were also placed around the construction site to provide detour information and to warn residents of construction dangers. In general, the entire block was closed to facilitate removal of the impacted asphalt and street reconstruction. However, in instances where the roadway is a primary transportation route, construction phasing and controls were established to maintain traffic access during peak usage hours. Sediment control devices were also installed at each storm sewer inlet that could potentially receive runoff from exposed impacted areas.

The interface between impacted and non-impacted zones was initially identified using a micro-R meter or a 2x2 sodium iodide (NaI) scintillation detector attached to a rate meter. The asphalt was wet saw cut adjacent to the identified interface. The saw cut was located to avoid cutting into the impacted asphalt. The sides of the street along the concrete gutter pan were also saw cut to allow the impacted asphalt to be segregated from the non-impacted concrete. Using the face of the curb as a guide, the saw was positioned so that only the concrete gutter was cut. Samples of the cuttings were collected, dried, and field counted to ensure that the radioactive materials have not been distrbed. If radioactivity was detected or a saw cut through an impacted area was required, the cuttings were contained and appropriately managed.

The impacted asphalt and associated subgrade were mechanically excavated and placed into 11-tonne (12-ton) capacity Lift Liners™ for subsequent transport and disposal. Each liner system consists of an inner and outer flexible bag constructed from a woven, coated polypropylene fabric. The liners meet the Department of Transportation (DOT) package requirements for the transport of radioactive materials. Smear samples were taken over an area of approximately 300 square centimeters (cm^2) along the outside bag surface at three random locations. The smears were counted onsite to ensure that the DOT removable contamination limits for gross alpha and beta activity specified in 49 CFR 173.443 were not exceeded.

Exposure rate measurements were also taken at the surface of each disposal bag prior to transport offsite. The average and maximum contact exposure rates recorded during the project were approximately 1 and 2.3 μSv/hr (100 and 230 μR/hr). All exposure rate measurements were below the DOT limit specified in 49 CFR 173.441 of 2 mSv/hour (200 mrem/hour). The filled bags were loaded by a crane onto a flatbed truck, and transported to a transload facility near Denver, where they were transferred into gondola rail cars and shipped to the U. S. Ecology disposal site near Simco, Idaho.

Contamination migration was controlled by utilizing localized water spraying/misting to prevent fugitive dust emissions during impacted asphalt excavation and loading. In addition, hauling vehicles and trailers were not allowed into the excavation zone. Work activities were also suspended when the sustained wind speed was excessive. Access into and egress from the active demolition area was controlled via an exclusion zone. Personnel and equipment exiting the exclusion zone were screened for radioactive contamination. Disposable boot covers were used and items were decontaminated when required. Exposed impacted asphalt was covered at the end of the work shift to further preclude inadvertent contact by the public and disturbance due to wind or rainfall.

AIR MONITORING

Sampling for airborne particulates was conducted during the removal operations to ensure that contaminant migration was not occurring. Five portable sampling stations were progressively moved on a daily basis and situated along the excavation perimeter. The samplers were continuously operated during impacted asphalt disturbance. Each air filter was counted in the field for alpha radiation approximately three and seven days after the collection date to allow decay of radon/radon progeny. The ambient air concentration was calculated based on the alpha count results and the amount of air sampled in accordance with NUREG-1400 [7]. All calculated concentrations were below the air effluent limit for Ra-226 of 33.3 Bq per liter (9e-13 μCi/mL) (10 CFR 20, Appendix B), which was established as the project ambient air limit. The air effluent limit is equivalent to the Ra-226 concentration which, if inhaled continuously by a member of the public over the course of a year, would result in a total effective dose equivalent of 50 millirem. Selected air filters were sent to an off-site laboratory for Ra-226 analysis using alpha spectroscopy. The laboratory results provided confirmation that the field calculated ambient air concentrations were less than established air effluent limit.

During the start of the project in 2003, workers were required to wear respirators until potential breathing zone exposure to radioactive airborne particulates could be determined. Workers performing tasks with the highest potential for dust generation wore lapel air samplers. The lapel samples were collected on a daily basis for several weeks and analyzed using alpha spectroscopy at an off-site laboratory. The Ra-226 concentrations were below the air effluent limiting all but one sample. To reduce potential for dust generation, the saw cutting procedures were modified to minimize cuts into the impacted asphalt layer. Based on the initial breathing zone results and changes to the saw cutting procedure, mandatory respiratory protection was discontinued. Periodic lapel sampling and aerosol dust monitoring were performed throughout the project. The results from this periodic monitoring and the daily perimeter air monitoring were used to verify that potential particulate generating activities were being appropriately controlled.

CONFIRMATION OF IMPACTED ASPHALT REMOVAL

Following demolition activities, radiation survey measurements and soil samples were collected to verify compliance with the ROD clean-up levels. The Uranium Mill Tailing Remedial Act (UMTRA) regulations (40 CFR 192) require residual Ra-226 activity to be less 185 Bq/kg (5 pCi/g) above background averaged over an area of 100 square meters (m^2). Based on previous work for the Denver Radium Superfund Sites, the Ra-226 background level for Denver was set at 74 Bq/kg (2 pCi/g). As such, the Ra-226 clean standard adopted for this project was 259 Bq/kg (7 pCi/g), which corresponds to the 185 Bq/kg (5 pCi/g) standard plus 74 Bq/kg (2 pCi/g) background.

The protocols listed in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) [8] were followed in developing and implementing the verification survey procedures. The remediated areas were designated Class 1 survey units per the MARSSIM guidance. As such, the entire subgrade surface and remaining surfaces that were in contact with impacted asphalt pavement (including curbs/gutters, manholes, and vault boxes) were scanned. A sodium iodide (NaI) gamma scintillation detector was used to allow broad area scanning for residual radioactivity. Based on the correlation between the impacted asphalt sample concentrations and gamma radiation readings performed by ARIX, a gamma exposure rate of 0.3 µSv/hr (30 µR/hr) at waist level was established to determine where additional removal was required. Typical background radiation level for Denver is approximately 0.2 µSv/hr (20 µR/hr). To provide additional conservatism, the project procedures required gamma scanning measurements be taken at surface level (less than 15 centimeters [6 inches] above the surface).

Direct alpha surface scanning was conducted for selected curb/gutter faces to document that the impacted asphalt was adequately removed from these interface points. The alpha surveying was performed along randomly selected 20-foot sections of curb/gutter. For each phase, approximately 10% of the curb/gutter surfaces were scanned for alpha activity. After confirming that alpha contamination was not present, non-impacted materials were handled as general construction waste.

Additional material removal or surface cleaning was performed when sustained elevated activity readings were encountered. Buried impacted asphalt associated with utility trenches was frequently detected and removed. The buried material was typically located near a service tap where a previous repair had been made. In some cases, buried material was encountered along the entire block where a new utility service was installed. After the additional impacted materials were removed, the areas were rescanned to verify that the exposure rate at the surface was less than 0.3 µSv/hr (30 µR/hr).

After field screening was completed, subgrade soil samples were collected and sent to an off-site laboratory for Ra-226 analysis either by alpha or gamma spectroscopy. The block was subdivided into a uniform grid to facilitate sample collection. One sample was collected near the center of each survey grid. The initial samples were analyzed using alpha spectroscopy to provide immediate results in the event that changes to the field surveying procedures were required. Field gamma spectroscopy was also initially performed on selected soil samples to validate the correlation between the gamma radiation measurements and the 259 Bq/kg (7 pCi/g) Ra-226 action level. After validating the field surveying procedures and correlations, soil samples were typically analyzed for Ra-226 using gamma spectroscopy with a minimum in-growth period of 21 days.

The laboratory results, in conjunction with the gamma radiation survey measurements, were statistically evaluated using the non-parametric, one-sample sign test per MARSSIM and NUREG-1505 [9]. The null hypothesis of the sign test specifies that the median Ra-226 result for the survey unit is greater than the 259 Bq/kg (7 pCi/g) release criterion. Each street block was assessed as a separate survey unit. The statistical testing was performed to reject the null hypothesis thereby demonstrating that the survey unit is suitable for free release without need of further management controls. Retrospective power curves were developed for each survey unit to show that the null hypothesis was correctly rejected given an accepted probability (e.g., $1 - \beta$). The power calculations were performed using the standard deviation and number of the Ra-226 results for each survey unit and critical values from MARSSIM for the sign test. The critical value was based on the total number of results and the desired confidence level (Type I [α] error). The decision error probabilities for testing the null hypothesis were set at 0.05 for both Type I (α) and Type II (β) errors.

The Ra-226 standard is averaged over 100 m^2. The statistical sign test was performed for the entire survey unit, which ranged in size from 580 to 1,820 square meters. Field scanning measurements provided the means to detect small, localized areas of elevated radioactivity. The sampling grid used to collect the soil samples was approximately 4.6 by 12.2 meters (15 by 40 feet). Soil samples were collected every 56 m^2 and therefore could be averaged over a 100 m^2 area. A hot-spot limit adjusted for the sample grid area calculated per Equation 1 was established as a comparison level for each individual sample result.

$$\text{Hot-Spot Limit} = \frac{100\ \text{m}^2}{56\ \text{m}^2} * 7\ \text{pCi/g} = 12.5\ \text{pCi/g} \qquad \text{(Eq. 1)}$$

In all cases, the evaluation of the sample results supported the free-release decision. These results and findings were submitted to the regulatory agencies to demonstrate that the ROD management and radiation controls are no longer required for the reconstructed streets. With restrictive management controls no longer required, future street maintenance will be less costly for the CCoD.

PROJECT SUMMARY

The impacted asphalt removal and street reconstruction was initiated in August 2002 with a limited effort to confirm removal techniques would allow preservation of the historical curbstones. The following year, full-scale removal operations began and have been implemented on an annual basis. A summary of the removal efforts and the projected remaining work is summarized in Table I.

The cost information for 2004 includes more than $3 million dollars (US) of capital improvements to the storm sewer infrastructure and other underground utilities. Combining the remediation and capital improvement projects between various the CCoD departments and utility owners resulted in a net overall reconstruction savings to taxpayers.

Table I. Summary of Completed and Remaining Impacted Asphalt Removal

	2002	2003	2004	2005	Future	Total
Number of Blocks	0.5	8.5	10	3	17	39
Impacted Area (square meters)	490	10,200	13,940	3,520	22,800	50,950
Impacted Asphalt (tonnes)	300	5,520	7,620	2,210	12,650	28,300
Impacted Asphalt Removal Cost (millions US dollars)	$ 0.3	$ 2.4	$ 2.6	$ 0.9	$ 5.9	$ 12.1
Total Project Cost (millions US dollars)	$ 0.3	$ 3.7	$ 6.6	$ 1.3	$ 8.9	$ 20.8

The removal of impacted asphalt from Denver streets is approximately 55 percent complete with a projected completion of 2007. The cost for removing the impacted asphalt at project completion is estimated to be $12.1 million dollars (US) with an additional $8.7 million dollars (US) for street reconstruction and infrastructure improvements.

CONCLUSIONS

The Denver Radium Street reconstruction project is being successfully implemented by Parsons for the CCoD. Removal of the impacted asphalt will result in less costly maintenance and repairs for the CCoD and utility owners in the future, as well as, eliminating a potential source of radiological exposure to neighboring residents and the surrounding environment. Ambient air monitoring, radiation surveys, and other health and safety monitoring verify that workers, public, and environment were not impacted during the removal and reconstruction efforts. To date, approximately 55 percent of the impacted asphalt has been removed. Under current funding commitments, the Denver Radium Street reconstruction project is expected to be completed in 2007.

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