Law Offices of Anthony J. Thompson, P.C.

1225 19th Street, NW., Suite 300
Washington, DC 20036
202-496-0780
Fax: 202-496-0783
(e-mail): ajthompson@athompsonlaw.com

June 30, 2004

SMB-1541
04008980

United States Nuclear Regulatory Commission
Region I Office
Attn: Mr. Ronald Bellamy
475 Allendale Road
King of Prussia, PA 19406

'04 JUL -1 A10:51

RECEIVED
REGION 1

Dear Mr. Bellamy:

By this letter, Heritage Minerals, Inc. (HMI) is providing the Nuclear Regulatory Commission's (NRC's) Region I office with a comprehensive update on the status of final decommissioning and decontamination (D&D) activities at the HMI site in Lakehurst, New Jersey. In addition, HMI is proposing a disposition pathway for all remaining materials at the site so that cost and time-efficient license termination can be achieved.

I. STATUS UPDATE AND PROPOSED DISPOSITION PLAN

As of the date of this letter, HMI has completed demolition of the wet and dry mill site buildings and has decontaminated the remaining resulting scrap materials to satisfy applicable NRC release guidance for *unrestricted use.* Such scrap materials have been removed from the HMI site. As a result of the demolition and decontamination process, HMI has accumulated approximately 300-400 tons of sands that were removed from the wet and dry mill buildings and from scrap materials during decontamination (i.e., by power washing). These sands were accumulated and stockpiled in one area of the HMI site (hereinafter "stockpile area"), and a disposition pathway for such materials needs to be determined.

HMI proposes that the disposition of these stockpiled sands be addressed along with other waste sands at the site (e.g., the so-called Blue/Grey Area), which NRC has determined are subject to the State of New Jersey's jurisdiction. As indicated in the Process History prepared by HMI, the wet and dry mill site buildings were used by site operators, including HMI, to remove saleable titanium mineral products (i.e., ilmenite, rutile, leucoxene, and zircon) from the heavy mineral fraction of the sands mined at the site. For a period of time just prior to the shutdown of active milling operations, HMI installed a monazite removal circuit at the end of the dry mill process to remove the monazite component of the heavy mineral fraction as a potentially saleable product.

HMI's production of a monazite stream in the dry mill led NRC to license the wet and dry mill buildings and the monazite storage pile, although HMI ceased all active processing operations prior to NRC issuing HMI's license.

When HMI determined that its active mineral processing operation was no longer economically viable and active mineral processing operations were terminated, any waste sands that did not reach the Blue Area for disposal remained within the wet and dry mill infrastructure (e.g., pipes, bucket elevators, tanks) and on the surface of equipment until HMI demolished and decontaminated the mill buildings and their infrastructure. During demolition and decontamination of these buildings, sands removed from various portions of the wet and dry mill buildings were placed in the aforementioned stockpile area. HMI's D&D contractor, ENERCON Services, performed a characterization survey of the materials in the stockpile area and determined that the stockpile sands have radiological characteristics similar to the Blue Area waste sands (i.e., 24-27 pCi/g total thorium and 24-25 pCi/g total uranium, which are well below NRC *licensable* source material levels).[1]

At no time were HMI's *wet* mill processing operations ever devoted to the concentration of a potential monazite product. HMI's wet mill utilized specific gravity mechanisms (i.e., Humphrey's spirals, shaker tables) to separate the heavy mineral fraction, which included titanium series minerals and accompanying monazite, from the lighter minerals in the mined sands. Sands containing the heavy mineral fraction eventually were sent from the wet mill to the dry mill for further processing, while the wet mill tailings were sent directly to a stockpile as "clean" material. While it appears that, at times, *licensable* levels of source material were present at the shaker tables, as a general proposition, wet mill processing *did not* create *licensable* source material.[2] Indeed, the dry mill "feed" material created in the wet mill and sent to the dry mill for processing was not *licensable* source material. As a result, since the vast majority of the sands processed in the wet mill exited as "clean" material or as dry mill feed, and concentrations of *licensable* source material were only present sporadically at some of the shaker tables, the in-process sands removed from the wet mill during demolition should not require NRC regulatory oversight.

The in-process sands removed from the *dry* mill building during demolition and decontamination, including any monazite faction, were either destined for disposal in the Blue Area as tailings or would have been contained in the saleable product, neither of which were *licensable* source material. As shown in the Process History, although *licensable* source material concentrations were created in various places in the dry mill circuits (mostly in magnetic circuits), neither the saleable product nor the wastes destined for the Blue Area contained *licensable* source material concentrations. The dry mill utilized only one circuit to concentrate monazite for a few months. Thus, the vast

[1] *See* Attachment A.
[2] Indeed, HMI's wet mill processing operations only used approximately 30 percent of the wet mill building's equipment during active processing operations.

majority of the sands removed from the dry mill during demolition and decontamination either were in a process that had not reached the monazite removal circuit or waste material that never made it to the Blue Area. In total, approximately 95 percent of the sands processed in the dry mill were removed as non-*licensable* saleable product or disposed of as tailings in the Blue Area. Had HMI's processing operations continued, after NRC licensing, the vast majority of the stockpiled sands that ultimately were removed from the dry mill building during demolition and decontamination would have been destined to be non-*licensable,* saleable product (if it was within the removal circuits themselves) or tailings for disposal in the Blue Area. Therefore, since the stockpiled sands do not exceed *licensable* source material levels, such sands should not be a matter requiring NRC regulatory oversight.

With the above-discussed factors in mind, HMI proposes that the stockpiled sands be addressed with the Blue Area as part of the final disposition plan to be developed with the State of New Jersey in accordance with its *Soil Remediation Standards for Radioactive Materials* (*Soil Remediation Standards*)[3] and performed under the Administrative Consent Order (ACO)[4] executed on November 19, 1993, with the New Jersey Department of Environmental Protection (NJDEP). This disposition pathway can be considered analogous to the option proposed by NRC Staff in the recent Transfer of Source Material Proposed Rule, which was to be created because "transfers [of "unimportant quantities" of such material] could potentially result in scenarios where exposure limits in 10 CFR Part 20 could be exceeded."[5] *See* 67 Fed. Reg. 55175, 55176 (August 28, 2002). This Proposed Rule would have allowed licensees to apply to NRC for permission to transfer waste materials below *licensable* source material levels to entities such as landfills and Resource Conservation and Recovery Act (RCRA) Subtitle C sites for final disposition if the transferring entity could demonstrate that no threat to public health and safety would exist as a result of that particular disposition pathway. Indeed, the Proposed Rule stated, "if the [transfer] approval request is for transfer for the purpose of direct disposal in an appropriate facility (*e.g.,* a RCRA Subtitle C facility authorized for such material or other disposal facilities having in place the appropriate State or EPA permits), the request for transfer would normally be approved if the dose to a member of the general public is unlikely to exceed 0.25 mSv/yr (25 mrem/yr)." *Id.* By analogy, had NRC Staff's Proposed Rule been approved by the Commission, HMI could have applied to NRC for permission to transfer jurisdiction over the stockpiled sands to the State of New Jersey which would require disposition of the stockpiled sands (and

---

[3] *See* State of New Jersey, *Soil Remediation Standards for Radioactive Materials*, N.J.A.C. 7:28-12.1 *et seq.* (2000).

[4] *See* Administrative Consent Order (ACO), Heritage Minerals, Inc. Site, Berkeley and Manchester Townships, ¶ 19 (November, 1993) ("The Department intends and Respondents agree that the scope of the investigation and cleanup required by this Administrative Consent Order will include all contaminants at the above referenced Site, and all contaminants which are emanating from or which have emanated from the Site.")

[5] The Commission declined to adopt this Proposed Rule, because NRC Staff failed to present an adequate health and safety basis for its promulgation.

other contaminated sands in all areas of the site contaminated by processing, including the so-called Red Area after release by NRC) in accordance with the aforementioned *Soil Remediation Standards*. Since HMI currently is bound by the above-noted ACO to "investigate and clean up" all contaminants at the site, including radionuclides, which will require it to satisfy New Jersey's 15 mrem/year standard to release the property for *unrestricted* use, including the planned construction of residential dwellings at the site, or perhaps other uses under a *restricted release* scenario, the proposed disposition pathway will have the same effect as approving removal to a State-permitted disposal facility. In addition, HMI is prepared to submit a written commitment to NRC that it will satisfy New Jersey's site release standards. Thus, transfer of the stockpile to New Jersey's jurisdiction along with other contaminated materials at the site should be accepted by NRC Staff as adequately protective of public health and safety.

II. PROPOSED ACTION PLAN

In order to achieve final site closure and license termination, HMI proposes that the following action plan be reviewed and accepted by NRC. Previously, the removal of all *fugitive licensable* source material from the NRC-licensed portion of the HMI site was effectuated in accordance with the May 6, 2003, letter submitted by HMI and approved by NRC. This letter required the excavation of *fugitive licensable* source material pockets (i.e., soil volumes defined by a surface footprint of sands with total thorium and uranium activities in excess of 116 pCi/g), until sampling confirmed that the sands *at the bottom* of the excavation area within the boundaries of the surface footprint were below 10 pCi/g total uranium and 10 pCi/g total thorium. Removal of these *fugitive licensable* source material pockets from excavation areas was completed by ENERCON in accordance with the May 6, 2003 letter. ENERCON's June 26, 2003 report, which was submitted to NRC, demonstrates that such excavation areas meet the requirements as delineated in the May 6, 2003 letter.

Later, on September 9, 2003, NRC's remediation contractor, the Oak Ridge Institutes for Science and Engineering (ORISE), conducted confirmatory sampling at the site and discovered additional *fugitive licensable* source material pockets. Each sample location was staked by ENERCON. Upon receipt and comparison of all ENERCON/ORISE sample data, ENERCON personnel returned to HMI's site to delineate, quantify, and record the GPS location of *licensable* source material. ENERCON personnel delineated and quantified those areas on October 1, 2003, using a Ludlum Model 44-10 sodium iodide instrument with lead columnator to locate each sample point. The area around each location was scanned to determine the surface footprint of *licensable* source material. Each location was augered on all sides and scanned vertically to determine the depth of *licensable* source material. These dimensions were used to estimate a volume of approximately 67 cubic yards of *licensable* source material destined for removal to International Uranium (USA) Corporation (IUSA) for processing as an alternate feed material.

As a result of this discovery and the continued discussions between HMI and NRC regarding the existence of a so-called "Red Area," HMI hereby submits a proposed NRC site boundary which is to encompass the entire NRC-licensed portion of the HMI site and which, technically, will separate the site areas covered by NRC's jurisdiction from those covered by New Jersey's jurisdiction prior to license termination. HMI has included within this *proposed final* NRC site boundary the *fugitive licensable* source material pockets identified by ORISE, the wet and dry mill building pads, the footprint of the former monazite pile storage area, and a reasonable buffer zone surrounding such locations as detailed in Attachment B. This proposed NRC-licensed area is based on a recent 100% gamma/GPS walkover survey of the so-called "Red Area." The area inside this proposed NRC site boundary was covered in a continuous gamma/GPS walkover survey that collected 18,280 readings. Locations exceeding 180,000 counts are shown and the larger ORISE-identified spots exceeding this count number are visible on the attached map. Other ORISE-identified spots are so small that they could not be seen on the scale of this map, so a "dot" was added to demonstrate that the exact locations of such spots are locatable for final disposition.

If this proposed site boundary is acceptable to NRC, ENERCON will address any remaining *fugitive licensable* source material pockets, including excavation of such material, placement of such material into appropriate shipping containers, and transportation of such material to IUSA's NRC-licensed uranium mill for final disposition. At the conclusion of any final excavation and removal of materials from the HMI site, no backfill will be placed in the areas where excavation occurs until necessary verification samples are completed. HMI requests that NRC be present to conduct split-sampling simultaneously with ENERCON's sampling prior to any later attempts to perform confirmatory sampling so that backfill does not fall back into the sampling location. After NRC and ENERCON complete their split sampling, HMI requests that both parties conduct a simultaneous "walkover" of the "Red Area" to verify that all *licensable* source material has been removed. ENERCON will provide a final report detailing the tasks completed, listing the results of all sampling, and providing a survey map of the final walk-over survey. Additionally, as noted above, HMI proposes that disposition of the stockpiled sands from demolition and decontamination of the wet and dry mill buildings be addressed with the Blue/Grey Area waste sands under the NJDEP ACO and the State of New Jersey's *Soil Remediation Standards*.

For your information, HMI is also attaching a map of the Radiation Science, Inc. (RSI) "background" sampling locations and a report prepared for HMI by SENES Consultants, Ltd. for submission to NJDEP as part of discussions with New Jersey regarding ultimate disposition of the *non*-NRC-licensed radionuclides in soils at the site (*See* Attachments C & D). If accepted by NRC, completion of the above-discussed tasks under its NRC license should result in the completion of HMI's obligations and the termination of its NRC license.

Thank you for your time and consideration in this matter, and please feel free to contact me at (202) 496-0780 if you have any questions.

Respectfully Submitted,

Anthony J. Thompson, Esq

ATTACHMENT A

ATTACHMENT A

STOCKPILE SAMPLES

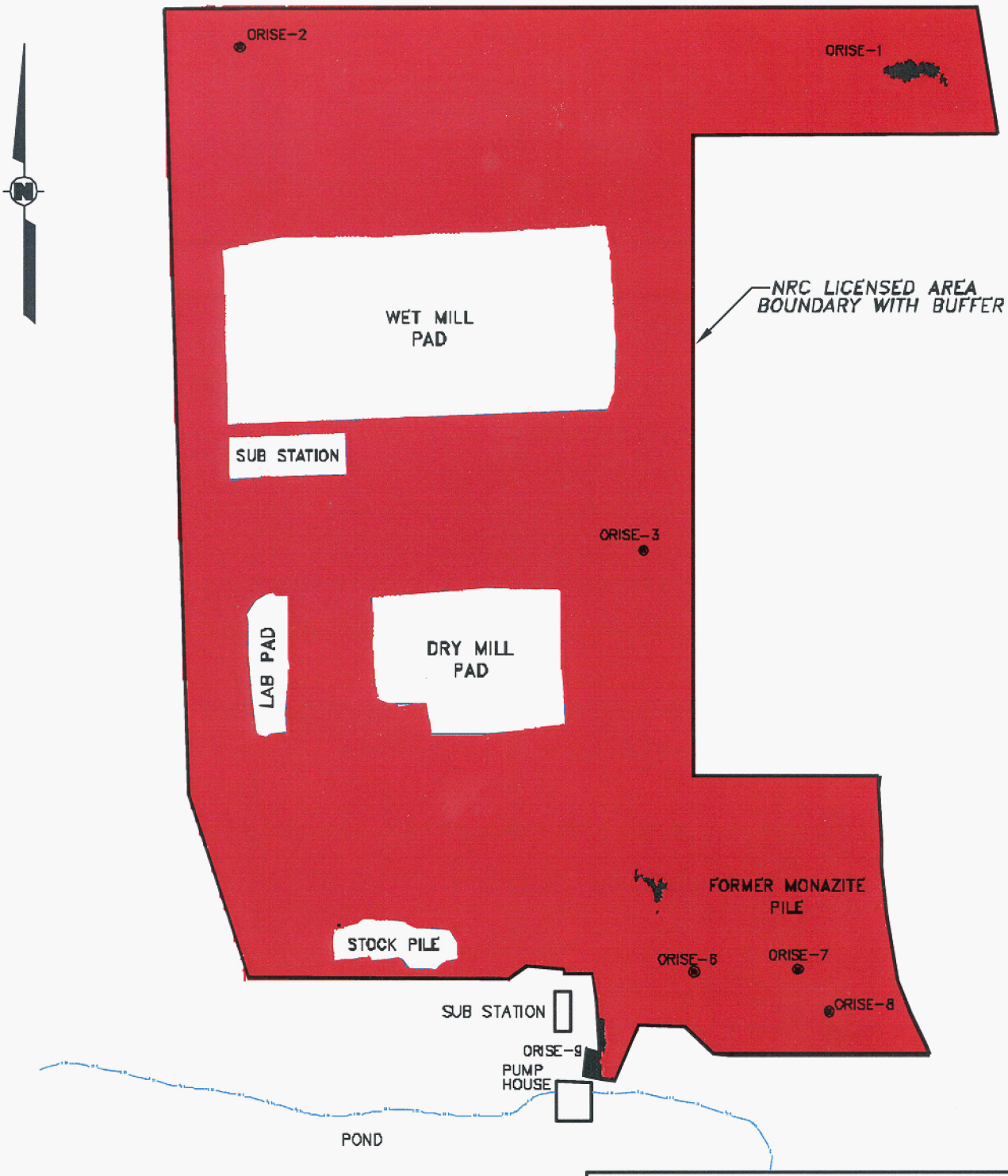
Sampled by	Total Thorium (pCi/g)	Total Uranium (pCi/g)
ENERCON SERVICES	27.7	25.9
ENERCON SERVICES	24.7	24.7
ORISE	27.3	20.0
ORISE	20.0	12.7
ORISE	26.1	32.0

Based on these five samples, the average thorium/uranium concentrations in the sands in the stockpile are approximately 25 pCi/g total thorium and 23 pCi/g total uranium.

Blue Area material concentrations reported by HMI in licensee submittals is approximately 120 parts per million of total uranium and thorium combined. When correlated based on activity, the blue area material as described by HMI should be approximately 21 pCi/g total thorium and 21 pCi/g uranium. These values show good correlation with the stockpile values and verify that the stockpile is consistent with the blue area material.

ATTACHMENT B

DRAWING NUMBER 99281A13



GAMMA SCAN SCALE

Color	Range Beg.	Range End
■	0.00	180000.00
■	180000.00	600000.00

FIGURE 1

NRC LICENSED AREA BOUNDARY WITH BUFFER

HERITAGE MINERALS
LAKEHURST, NEW JERSEY

PREPARED FOR
ENERCON SERVICES, INC.
MURRYSVILLE, PENNSYLVANIA

CUMMINGS RITER CONSULTANTS, INC.

DRAWING NUMBER 99281A13

REVISION	DATE	DESCRIPTION

DRAWN BY:	T.E. McKee	DATE:	6-8-04
CHECKED BY:		DATE:	
APPROVED BY:		DATE:	

ATTACHMENT D

PATHWAYS ANALYSIS AND SITE-SPECIFIC OPTIONS FOR ASARCO/HMI SITE

Prepared for:

H. Hovnanian Industries
4000 Route 66
Tinton Falls, New Jersey
07753

Prepared by:

SENES Consultants Limited
121 Granton Drive, Unit 12
Richmond Hill, Ontario
L4B 3N4

February 2003

Printed on Recycled Paper Containing Post-Consumer Fibre

EXECUTIVE SUMMARY

The Heritage Minerals, Inc. (HMI) site in New Jersey contains naturally occurring levels of radionuclides that are slightly elevated compared to background levels due to the past processing of heavy mineral sands containing naturally occurring levels of radionuclides. The physical processing of these minerals has resulted in technologically enhanced naturally occurring radioactive material (TENORM) on the site that potentially exceeds New Jersey Department of the Environment (NJDEP) criteria for unrestricted property use.

This report discusses potential site-specific options for addressing those areas with slightly elevated levels of naturally occurring radionuclides at the HMI site to satisfy NJDEP site use criteria including radioactive dose, indoor radon levels and protection of groundwater. Detailed engineering planning and cost estimates have not been developed for these options; however, the technical feasibility, regulatory precedents, and radioactive dose implications for each approach are discussed.

The TENORM nature of the radionuclides and the physical characteristics of the heavy minerals containing naturally occurring radionuclides provide a basis for site-specific options. A critical factor is the chemical characteristics of heavy minerals that results in radioactive equilibrium within the minerals, low radon emanation compared to normal soils, and insolubility with respect to ingestion or leaching to groundwater. These aspects support the derivation of site-specific derived concentration guideline levels (DCGLs) that are less restrictive than the default values provided by NJDEP.

The existing site characterization data, derived from an NJDEP-approved plan, have been used to estimate the volumes and radionuclide concentrations in materials to be addressed. Additionally, a review of site-specific background characterization studies indicates that background concentrations likely were underestimated in the past.

Two site-specific options have been considered. The first option is consolidation of the material with slightly elevated concentrations to one area with State enforced institutional controls allowing only recreational uses. Radiological doses under this first option would be considerably lower than State criteria and would meet dose criteria if the institutional control were to fail. The second option would be to return the slightly elevated material to its original location by placing the material at the bottom of the lakes originally created by on-site dredging/mining of the ore. In effect, this second option returns the TENORM material to its place in nature. Under both site-specific options, the planned development area meets the NJDEP requirements for unrestricted release.

The second option, specifically the return of the TENORM material to its original place in nature, is the preferred option due to lower radiological dose, no requirement for institutional controls, and a lack of technical complexity.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The Heritage Minerals, Inc. (HMI) site in New Jersey contains naturally occurring radionuclide levels that are slightly elevated compared to natural background levels due to the past processing of heavy mineral sands containing naturally occurring levels of radionuclides. The purely physical processing of these heavy mineral sands has resulted in the presence of technologically enhanced naturally occurring radioactive material (TENORM) at the HMI site that potentially may exceed New Jersey Department of Environmental Protection (NJDEP) criteria for unrestricted property use.

Existing HMI site characterization data, based on an NJDEP approved plan, have been used to estimate the volume of materials containing slightly elevated levels of radionuclides. Additionally, a review of site-specific background characterization studies indicates that background concentrations at the HMI site likely were underestimated in the past.

Two potential site-specific options that have been considered are consolidation of the TENORM material to one area with State enforced institutional controls (i.e. deed restrictions) allowing only recreational use (i.e. *limited* restricted use) thereby allowing the development area to satisfy NJDEP unrestricted site use criteria and returning the TENORM material to the bottom of the lakes created by the original dredging/mining of the original ore. In effect, this later option returns the TENORM material to its place in nature. Under both site-specific options, the planned development area meets the NJDEP requirements for unrestricted site use.

This report focuses on potential site-specific options for those areas of the HMI site containing the TENORM material, and it will discuss how these options will satisfy NJDEP unrestricted site use criteria including criteria for radiation dose, indoor radon levels and groundwater protection. Detailed engineering planning and cost estimates have not yet been developed for these options; however, the technical feasibility, regulatory precedents, and radioactive dose implications for each approach will be discussed.

The general outline of the report is as follows:

- Chapter 2 provides a brief historical description of the HMI site and processing operations, including some discussion of TENORM material and secular equilibrium relative to the heavy mineral fraction.

- Chapter 3 discusses the development of alternate concentration guideline values based on site-specific conditions; specifically, the physical and chemical characteristics of the heavy minerals fraction which results in ingestion, including groundwater pathways,

being irrelevant to a dose assessment due to the insolubility of and the low radon emanation from heavy minerals, the latter of which substantially reduces potential indoor radon doses. Derived Concentration Guideline Levels (DCGLs) based only on external gamma exposure and inhalation are developed for the natural uranium and thorium series for a representative range of remediation scenarios.

- Chapter 4 discusses the site-specific radiological characterization, including background characterization data for the HMI site, primarily from the MTRAP characterization study (CDM 1998). Volumes of TENORM material to be addressed from the areas of concern (AOCs) are estimated for the site-specific options.

- Chapter 5 describes the two site-specific options for the AOCs with different requirements for institutional controls.

- Chapter 6 summarizes the report findings and suggests areas for possible refinement.

2.0 SITE HISTORY

In 1957, ASARCO, Inc. (ASARCO) explored the area around what is now the HMI site for deposits of titanium-bearing heavy minerals, which were reportedly to be found in Ocean County's underlying sedimentary formations. At that time, ASARCO optioned approximately 20,000 acres of land in Manchester Township and, in 1960, after three years of exploration, ASARCO purchased approximately 9,000 acres for mineral recovery of which 7,000 acres currently remain under HMI's control.

After purchasing these 9,000 acres of land in 1960, ASARCO placed the site on standby status until 1968. In 1968, ASARCO began the design and construction phases for its mineral recovery plant. The design and construction phases lasted about five years until 1973 when ASARCO's mineral recovery operations commenced.

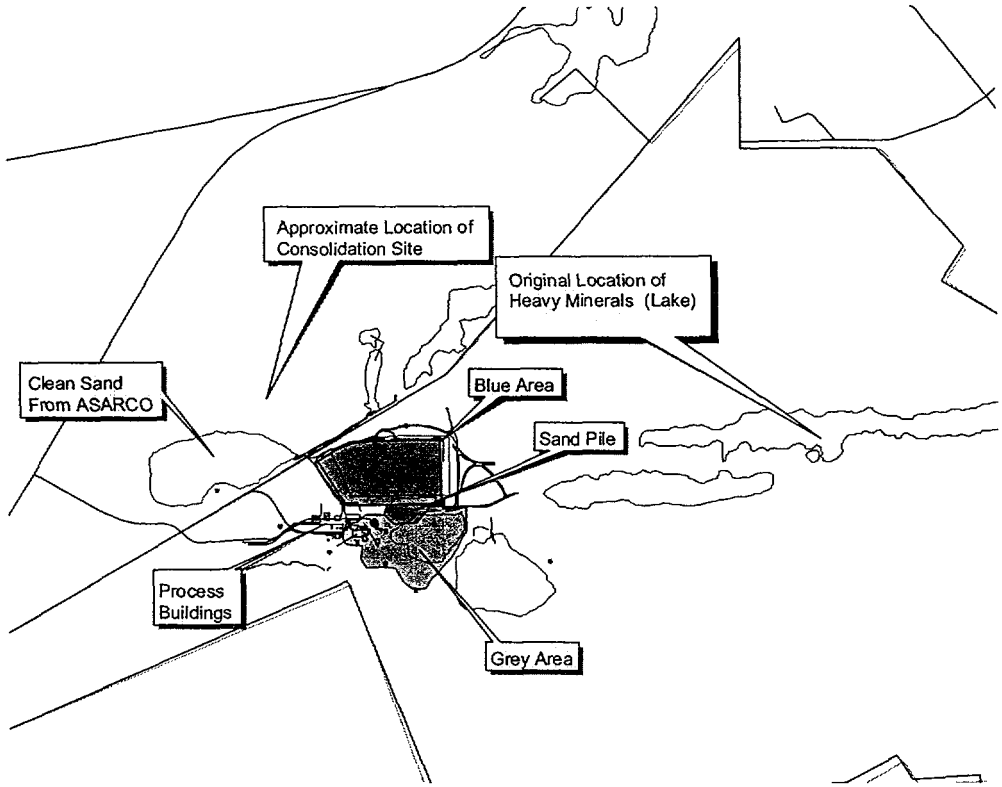
The plant facilities designed and constructed by ASARCO are situated in the center of the mined area of the property. The wet mill building is a three-story steel structure erected on a 229' X 99' concrete slab, and the dry mill building is also a three-story steel structure erected on a 120' X 95' concrete slab. Additional buildings at the HMI site include the laboratory, the service building, the warehouse, the change house, the compressor house, and the main office building.

Since mineral recovery operations began in 1973, the HMI site has been owned and/or operated by four (4) different companies, ASARCO, Humphrey's Gold, Mineral Recovery, Inc. (MRI) and HMI. Each company utilized the same general mineral recovery process with some variations depending on which heavy mineral each company sought to recover. One consistent factor in the mineral recovery processes used at the HMI site is the absence of any chemicals. Mineral recovery operations only utilized gravity and electrostatic and electro-magnetic processes to separate and recovery heavy minerals from the dredged/mined sands. These processing operations will be discussed in greater detail below.

2.1 SITE LOCATION

The HMI site is located in Lakehurst, NJ, (located in Manchester Township, Ocean County) approximately 75 miles south of New York City in the New Jersey Coastal Plain. The plant entrance is located at Mile Marker 41 on New Jersey State Highway No. 70 and 12 miles west of the Garden State Parkway. This area is characterized by fine to coarse sandy soils, gravels, and clays that geologically were formed by an estuary. Figure 2.1 shows the general property outline along with areas that were involved in the processing of heavy minerals at the site. A brief discussion of these areas and the process history are included in the following sections.

FIGURE 2.1
SCHEMATIC SITE MAP



2.2 SITE PROCESS ACTIVITY

2.2.1 ASARCO Mineral Recovery for Ilmenite

ASARCO's mineral recovery operations began in 1973 and continued until March of 1982 and were primarily focused on the recovery of the titanium mineral ilmenite. Its mineral recovery operations consisted of hydraulic mining (dredging) of sand deposits on-site which were identified as containing economic levels of ilmenite. These sand deposits also contained a variety of titanium-bearing minerals such as leucoxene and rutile as well as other heavy minerals including zircon, kyanite, sillimenite and monazite.

ASARCO's mining (dredging) operations involved the removal of topsoil overlying the areas where recoverable ilmenite was located and stockpiling such topsoil for future use during site reclamation. Dredging operations were conducted to a maximum depth of approximately 80 feet

and broke sand deposits into recoverable sizes which were removed from the ore zone as a slurry. The dredge was advanced through the mining zone in a walking-type advance at a rate of 100 feet per week creating a path approximately 120 feet wide. About 12.3 million yd^3 of sand containing heavy minerals was extracted during the dredging/mining stage with a nominal grade of 5% heavy minerals. The end result of this dredging/mining activity was the lakes currently at the HMI site which are approximately 80 feet deep: the majority of heavy minerals and the accompanying naturally occurring radionuclides that were extracted at the HMI site were originally present at the bottom of these lakes.

The dredged/mined ore was then fed to the wet mill where it was screened for oversized materials, which were rejected from the process and returned to the dredge pond or stockpiled as clean gravel. The remaining dredged material was introduced to a concentrating circuit containing Humphrey spirals where ilmenite (heavy minerals) was separated from silica sands (lighter minerals) by gravity. The lighter silica sands were returned to the dredge pond as backfill, and the heavy mineral concentrate was fed to a final finisher for further concentrating. The resulting wet mill heavy mineral concentrate, which contained approximately 95 percent of the heavy minerals originally dredged, including ilmenite and monazite, was then stored on the ground east of the wet mill to de-water. The de-watered concentrate was then moved using front-end loaders to the dry mill feed hopper for insertion into the dry mill process. Any residual material left on the ground east of the wet mill was graded and re-graded on the surface and into the subsurface to maintain level ground for future storage and de-watering of wet mill concentrates. Spills of material also occurred during the loading of heavy mineral concentrates from the wet mill process prior to insertion into the dry mill process. This occurred because front-end loaders were used to transport wet mill concentrates from the wet mill storage area to the dry mill.

It is crucial to note that the dry mill process used by ASARCO was composed of various units including conveyor belts, bucket elevators, and a series of electrostatic and electromagnetic separators in an *integrated* mineral recovery process. The proper operation of the dry mill required that, depending on their location in the dry mill circuit(s), the various electrostatic and electromagnetic separators be calibrated to the ore grade at that point in the process to maximize mineral recovery. Thus, the dry mill process relied heavily on the continuous and simultaneous operation of these units.

When any one component of any dry mill unit required repair or replacement, the dry mill could not produce a final ilmenite product. In order to avoid total dry mill shutdown, which would have cost approximately $120,000 per hour, ASARCO initiated a procedure ("Mill Shutdown Avoidance Procedure) of continuing to run the dry mill while replacing any malfunctioning components. To do this, the dry mill process was essentially "short-circuited" and the in-process feed material was conveyed through portals cut in the dry mill's walls onto the ground south of

the dry mill for future re-insertion into the dry mill process.

This Mill Shutdown Avoidance Procedure resulted in feed materials from various stages of the dry mill process, which contained various concentrations of heavy mineral being piled on the east and south sides of the dry mill. This material was used for general site grading and, depending on the process stage, contained slightly elevated levels of radionuclides in varying concentrations.

In summary, slightly elevated radionuclide levels arising from ASARCO operations primarily comprise the heavy mineral fraction stockpiled on the Grey Area with some slightly elevated naturally occurring radionuclides in the sediments at the bottom of the settling ponds located in the Blue Area and in other areas arising from spills or process upsets in the ASARCO plant.

2.2.2 Humphrey's Gold Mineral Recovery Operations

In April of 1982, ASARCO leased the HMI site to Humphrey's Gold for the purpose of conducting a plant-scale pilot test using the tailings from ASARCO's ilmenite recovery operations to determine if a commercial grade zircon product could be economically produced. ASARCO's lease with Humphrey's Gold was to last six (6) months, although Humphrey's Gold performed pilot tests for only one (1) month. ASARCO was not directly involved in Humphrey's Gold's pilot tests.

With the exception of limiting the amount of feed materials introduced into the dry mill process, Humphrey's Gold utilized the ASARCO mineral recovery processes in the same manner as ASARCO. However, the greatly reduced volume of feed material introduced into the dry mill process resulted in such feed materials being unsuitable for processing. Thus, Humphrey's Gold's mineral recovery operations lasted only one (1) month. Tailings and any product generated from Humphrey's Gold mineral recovery operations were pumped to the northeast section of the Grey Area for stockpiling.

2.2.3 Mineral Recovery, Inc. Mineral Recovery Operations

In 1986, HMI purchased the site from ASARCO and leased the plant facilities to MRI. When MRI began mineral recovery operations at the HMI site, it sought to recover zircon, leucoxene, and rutile from the tailings created by ASARCO. In order to engage in such activity, MRI altered the ASARCO dry mill process to include additional mechanisms allowing for further separation of heavy minerals so that zircon, leucoxene, and rutile recovery could be maximized.

MRI started mineral recovery operations in October of 1986 and continued such operations until August of 1987 when HMI assumed the management and control of the site.

2.2.4 Heritage Minerals Inc. Mineral Recovery Operations

After MRI's lease was terminated in August of 1987, HMI assumed control of the site and commenced operations to process ASARCO's tailings in the Grey Area for the recovery of zircon, leucoxene, and rutile.

The dry mill process employed by HMI was fundamentally similar to that used by ASARCO during its mineral recovery operations. However, since HMI was attempting to recover zircon as its main product and leucoxene and rutile as byproducts, the HMI dry mill process did contain some variations from the ASARCO dry mill process.

HMI conducted mineral recovery operations in two separate phases. During Phase I, the dry mill process was divided into two distinct process circuits, the Leucoxene and Zircon Circuits. HMI processed the remaining tailings created by ASARCO to recover their zircon, leucoxene and rutile content. Tailings from HMI's Phase I operations were stockpiled in the Blue Area.

When the dry mill tailings created by ASARCO were depleted by HMI's Phase I mineral recovery operations, HMIs Phase II mineral recovery operations were initiated. Initially, HMI conducted tests to determine whether sufficient amounts of zircon and leucoxene remained in the Blue Area tailings to warrant reprocessing them for zircon and leucoxene recovery. After these tests were concluded, HMI determined that there were sufficient quantities of zircon and leucoxene available for reprocessing. At this point, HMI began to reprocess the Blue Area tailings using the same wet and dry mill processes described above.

HMI used the same Mill Shutdown Avoidance procedures as ASARCO during its mineral recovery operations and placed heavy mineral concentrates on the ground south and east of the dry mill when a component of the dry mill process malfunctioned. While it attempted to return this stockpiled material to the dry mill process, HMI was unable to do so because the material's heavy mineral concentrations were too high to meet the ore grade calibrations of the dry mill process. This resulted in stockpiled materials being graded and re-graded on the surface and into the subsurface east and south of the dry mill building.

2.2.5 Areas of Concern

On the basis of process history, there are four areas of concern (AOC) relative to slightly elevated levels of naturally occurring radionuclides. The first area is the Grey Area where heavy mineral tailings from the original ASARCO operations were placed. Although these tailings were re-processed by HMI for zircon recovery, there may be residual ASARCO tailings remaining in the Grey Area as well as materials arising from surface grading of overflow materials.

The second AOC is the Blue Area where the tailings from HMI mineral recovery operations for zircon were placed. These tailings would generally have higher levels of naturally occurring radionuclides than the original tailings in the Grey Area. The Blue Area also contains the sediments from the bottom of the settling ponds used during ASARCO's mineral recovery operations.

The third AOC is the Sand Pile which contains tailings produced during the recovery of monazite from tailings in the Blue Area. The levels of naturally occurring radionuclides in this material are generally expected to be lower than that of materials located in the Grey or the Blue Area.

The final AOC is the "Mill Vicinity" area where slightly elevated levels of naturally occurring radionuclides are present due to the use of overflow materials from the milling process for site grading.

2.3 TENORM

The slightly elevated levels of naturally occurring radionuclides at the HMI site can be considered to be TENORM since the radionuclides were naturally present in the ore mined on the property. Radionuclides were not introduced into the materials nor were radionuclides brought onto the site from outside sources. The slightly elevated radionuclide concentrations are the result of the physical separation of heavy minerals containing naturally occurring radionuclides without the use of chemicals.

The TENORM material is present in varying concentrations in soils at the HMI site depending on the relevant process history. In some cases, the concentrations of radionuclides were sufficiently high that the materials were classified as *licensable* source material by the Nuclear Regulatory Commission (NRC). This classification was applied to the monazite pile that was shipped off site. The monazite fraction of the heavy mineral sands contains most of the naturally occurring radionuclides present in the soils at the site.

2.4 Heavy Minerals and Equilibrium in the Natural Decay Series

Naturally occurring radionuclide concentrations in heavy minerals typically are in secular equilibrium (Paschoa *et al* 1993, Kerrigan and O'Connor 1990). Process knowledge of the site indicates that, since no chemical separation (i.e. chemical processing which might result in chemical changes to the minerals including dissolution of radionuclides in the heavy mineral fraction) of the heavy minerals occurred, **in our opinion, it is reasonable to assume (secular) equilibrium within the uranium-238 and thorium-232 decay chains.**

3.0 ALTERNATE CONCENTRATION CRITERIA

NJDEP provides "default" DCGLs for radionuclide concentrations at sites; however, alternate DCGLs can be proposed based on relevant site-specific information. This chapter describes the technical basis for alternate DCGLs at this site based in large part on the insolubility of heavy minerals due to the absence of any chemical processing. The insolubility of the heavy minerals renders the groundwater and ingestion dose pathways irrelevant and their physical structure results in the radon emanation coefficient from the heavy mineral fraction being much lower than from typical soils. The radioactive equilibrium in the heavy mineral fraction means that only *one* radionuclide from each of the natural uranium and natural thorium series need be considered in establishing DCGLs.

In general terms, the intended use of the development site will be residential slab-on-grade construction for a retirement community. Other areas of the HMI site are intended for use as open areas (e.g., no residential or commercial development).

3.1 NJDEP PATHWAYS ANALYSIS AND DEFAULT CONCENTRATION GUIDELINES

NJDEP has established unrestricted use standards for sites containing elevated levels of radionuclides (NJDEP 2000). The primary standards include a total effective dose equivalent from intake and external radiation dose of 15 millirem per year (mrem/y) above background, an incremental indoor radon concentration of less than 3.0 picocuries per litre (pCi/L) and groundwater radionuclide concentrations which satisfy the relevant New Jersey Groundwater Quality Standards (7:28-12.9(a)).

3.1.1 NJDEP Pathways Model

The NJDEP regulations provide for calculation of alternate DCGLs where site-specific physical factors, waste-specific factors or design factors may make use of such alternatives which are more appropriate than the "default" DCGLs (7:28-12.9(c)). A pathways analysis may be conducted with a computer model acceptable to NJDEP (7:28-12.9(h)). NJDEP has created a spreadsheet, *NJRaSoRS5.xls*, that is considered acceptable for calculating alternate DCGLs, and this spreadsheet has been utilized in the present assessment.

3.2 SITE-SPECIFIC CONSIDERATIONS FOR DERIVATION OF ALTERNATIVE CONCENTRATION GUIDELINES

NJDEP has indicated that alternate DCGLs can be pursued. At the HMI site, the major site-specific consideration is the chemical and physical characteristics of heavy minerals.

3.2.1 Physical/Chemical Properties of Heavy Mineral Fraction

The heavy mineral fraction which contains virtually all of the naturally occurring radionuclides contains very stable compounds such that the radionuclides are unavailable for transport through the environment (e.g. leaching to groundwater or chemical uptake by vegetation). In a similar manner, the release of radon from the heavy mineral fraction is much lower than the release of radon from typical soils. These physical and chemical characteristics of the heavy mineral fraction are the critical considerations in the derivation of alternate guideline values

Solubility/Bioavailability

The heavy minerals at the HMI site are of a type(s) which are stable chemically and physically such that the contained radionuclides do not leave the mineral structure under normal environmental conditions after their initial formation. Heavy minerals, such as zircon, are so stable that materials containing these minerals can be dated more than 2 billion years into the past based on the relationship between the activities of uranium and lead radionuclides within the zircon. These types of heavy minerals like these are even resistant to chemical breakdown in hydrochloric acid and often require the more aggressive hydrofluoric acid to dissolve minerals and release radionuclides. These heavy minerals are therefore considered stable under environmental conditions and are not available for chemical uptake by vegetation or leaching to groundwater. This is consistent with the NRC's statement that heavy minerals at the site are stable and that water samples show no increase in radioactive contamination (NRC 1993). Recent groundwater measurements at the site show radionuclide concentrations at background levels and, therefore, it can be concluded that the dissolution of radionuclides is not occurring (CDM 1998).

The insolubility of heavy minerals results in secular equilibrium of the radioactive decay series with the radionuclides remaining within the matrix. Thorium series equilibrium was investigated in a typical Western Australian monazite, and it was concluded that secular equilibrium could be assumed when estimating individual radionuclide activity in monazite from the gross alpha activity (Kerrigan and O'Connor, 1990).

Radon Emanation Coefficient

The radon emanation coefficient is the proportion (fraction) of radon atoms that are created from the radioactive decay of radium within the mineral grain that escape into interstitial spaces. These radon atoms then become available for diffusion through the soil and potentially for entry into buildings. Radon emanation in soils have been reported at 0.25 (Megumi and Mamro, 1974) and averaging 0.23 from a range of 0.02 to 0.83 (UNSCEAR, 1993). Radon emanation coefficients for heavy minerals like those at the HMI site are much lower due to their physical structure. Radon emanation coefficients from zircon were reported to be 0.017 ranging from 0.0017 to 0.048 in 28 samples from Finland and 0.031 ranging from 0.002 to 0.12 in 29 other samples (Barretto 1975). Emanation coefficients of Rn-220 from monazite have been reported as 0.0002 for dry samples (Kerrigan 1990), 0.002 (Barretto 1975) and 0.0036 (as reported by Kerrigan 1990). Radon emanation rates from uncovered ores were in most cases lower than the emanation rate from soils (Harrington 1993).

The literature indicates that radon emanation coefficients from such heavy minerals fractions are about a factor of 10 or more lower than the radon emanation coefficient for typical soils. It follows that the indoor radon concentrations potentially attributable to radionuclides in the heavy minerals located at the HMI site would be at least 10 times lower than the corresponding indoor radon concentrations from typical soils with the same radium concentration. The NJDEP pathways analysis for radon uses a factor of 1.5 pCi/L per pCi/g to relate indoor radon concentrations to soil concentrations. On the basis of lower radon emanation coefficients for the heavy minerals fraction, a factor of 0.15 pCi/L per pCi/g would provide a conservative estimate of the indoor radon concentration arising from heavy minerals and has been used in this assessment. This is consistent with findings that low levels of radon are present where heavy minerals are processed (Hewson 1990, Johnston 1991, Koperski 1993).

3.2.2 Land Use Scenarios

Residential structures will be constructed in the development area with lot sizes ranging up to approximately 71 ft by 110 ft. The lot sizes for residences built under failure of institutional control scenario are unknown. For this analysis, we have assumed that the lot size is the same, 10890 ft^2, as the NJDEP default values.

3.3 ALTERNATE DCGLS FOR HERITAGE SITE SOILS

Alternate DCGLs have been calculated for HMI site soils based on two site-specific conditions:

1. First, the chemical and physical characteristics of the radionuclides are such that they are not mobile in the environment and, therefore, the intake pathways (groundwater, soil ingestion, and crop ingestion) are not applicable at this site.
2. The radon emanation factor for heavy minerals is much lower than the default value used by NJDEP.

3.3.1 NJDEP Default Dose Factors

Dose factors (mrem per pCi/g) were calculated using the NJDEP pathways model for various selected vertical extents of contamination (VE) and depths of uncontaminated surface soil (USS). Radionuclides within each of the natural uranium series and thorium series were considered to have the same activity (i.e. to be in equilibrium) due to the physical and chemical nature of the heavy mineral fraction. The natural U-235 series was assumed to have 5% of the activity of U-238 (While NJDEP usually does not consider U-235 in its analysis, we have considered it here for completeness).

The dose factors were summed to provide a single dose factor for the uranium and thorium decay series. Table 3.1 shows the dose factors from the external radiation and inhalation pathways along with the dose factors for all pathways that are usually considered by NJDEP provided in brackets. In general, the dose factors (per pCi/g) for thorium are slightly higher than the dose factors for uranium primarily due to the higher external radiation dose from the thorium series compared to the uranium series. The dose factors from the thorium series range from 9.8 mrem per pCi/g for basement construction with 9 ft vertical extent of contamination (VE) and 0 ft uncontaminated surface soil (USS) to 0.8 mrem per pCi/g for slab-on-grade construction with 1 ft VE and 3 ft USS. Obviously, the dose factor depends on construction type, the vertical extent of contamination, and the thickness of uncontaminated surface soil.

TABLE 3.1
DOSE FACTORS (mrem per pCi/g) FROM EXTERNAL GAMMA RADIATION AND INHALATION FOR RESIDENTIAL SCENARIO BASED ON NJDEP DEFAULT ANALYSIS

		Vertical Extent of Contamination (VE)		
Construction Type	**Natural Decay Series**	**1 ft VE**	**5 ft VE**	**9 ft VE**
0 ft of uncontaminated surface soil (USS)				
Basement	Thorium	5.9 (6.9)	7.8 (9.2)	9.8 (11.2)
	Uranium	4.1 (6.6)	5.4 (10.0)	6.9 (12.8)
Slab-on-Grade	Thorium	6.6 (7.4)	6.6 (8.0)	6.6 (8.0)
	Uranium	4.6 (6.7)	4.6 (9.2)	4.6 (10.5)
1 ft of uncontaminated surface soil (USS)				
Basement	Thorium	1.2 (1.7)	6.2 (7.4)	9.8 (11.2)
	Uranium	0.9 (2.3)	4.3 (8.6)	6.9 (12.8)
Slab-on-Grade	Thorium	1.9 (2.4)	4.2 (5.6)	4.2 (5.6)
	Uranium	1.4 (2.8)	2.9 (7.6)	2.9 (8.8)
2 ft of uncontaminated surface soil (USS)				
Basement	Thorium	1.2 (1.7)	6.2 (7.1)	8.6 (9.6)
	Uranium	0.9 (2.3)	4.3 (7.9)	6.0 (11.1)
Slab-on-Grade	Thorium	0.9 (1.3)	2.4 (3.3)	2.4 (3.3)
	Uranium	0.6 (2.0)	1.7 (5.4)	1.7 (6.7)
3 ft of uncontaminated surface soil (USS)				
Basement	Thorium	1.2 (1.4)	6.2 (6.7)	7.4 (7.9)
	Uranium	0.9 (1.8)	4.3 (7.2)	5.2 (9.4)
Slab-on-Grade	Thorium	0.8 (1.2)	1.5 (2.0)	1.5 (2.0)
	Uranium	0.5 (1.9)	1.1 (3.9)	1.1 (5.2)

Notes:
Dose Factors are summed over the natural decay series radionuclides assuming equilibrium.
Number in brackets is Dose factor including all Pathways.
Uranium series includes U-235 decay series radionuclides at 5% of U-238 series.

Table 3.1 includes, in parentheses, the dose factors if the ingestion pathways were included for comparison purposes.

3.3.2 Alternate DCGLs

Alternate DCGLs for the natural uranium and natural thorium series have been estimated by dividing the 15 mrem standard by the dose factor for the decay series with the ingestion pathways excluded (due to the insolubility of the heavy minerals). Table 3.2 shows the DCGLs

for basement and slab-on-grade residential construction. As expected, due to the higher gamma radiation emissions from thorium, the DCGLs for the thorium series are lower than the DCGLs for uranium series. The DCGLs range from 1.5 pCi/g to19.6 pCi/g for the thorium series. The numbers in parentheses are the DCGLS using NJDEP default pathways parameters.

TABLE 3.2
DCGL (pCi/g) FOR RESIDENTIAL SCENARIO
BASED ON NJDEP DEFAULT ANALYSIS OF EXTERNAL RADIATION AND INHALATION PATHWAYS

		Vertical Extent of Contamination (VE)		
Construction Type	**Natural Decay Series**	**1 ft VE**	**5 ft VE**	**9 ft VE**
0 ft of uncontaminated surface soil USS)				
Basement	Thorium	2.5 (2.2)	1.9 (1.6)	1.5 (1.3)
	Uranium	3.6 (2.3)	2.8 (1.5)	2.2 (1.2)
Slab-on-Grade	Thorium	2.3 (2.0)	2.3 (1.9)	2.3 (1.9)
	Uranium	3.2 (2.2)	3.2 (1.6)	3.2 (1.4)
1 ft of uncontaminated surface soil (USS)				
Basement	Thorium	12.1 (9.0)	2.4 (2.0)	1.5 (1.3)
	Uranium	17.3 (6.7)	3.5 (1.7)	2.2 (1.2)
Slab-on-Grade	Thorium	7.8 (6.3)	3.6 (2.7)	3.6 (2.7)
	Uranium	11.1 (5.4)	5.1 (2.0)	5.1 (1.7)
2 ft of uncontaminated surface soil (USS)				
Basement	Thorium	12.1 (9.0)	2.4 (2.1)	1.7 (1.6)
	Uranium	17.3 (6.7)	3.5 (1.9)	2.5 (1.4)
Slab-on-Grade	Thorium	17.2 (11.4)	6.3 (4.5)	6.3 (4.5)
	Uranium	24.6 (7.4)	9.0 (2.8)	9.0 (2.2)
3 ft of uncontaminated surface soil (USS)				
Basement	Thorium	12.1 (10.5)	2.4 (2.2)	2.0 (1.9)
	Uranium	17.3 (8.4)	3.5 (2.1)	2.9 (1.6)
Slab-on-Grade	Thorium	19.6 (12.8)	9.9 (7.4)	9.9 (7.4)
	Uranium	28.0 (8.0)	14.1 (3.8)	14.1 (2.9)

Note:
Numbers in brackets are the DCGL with NJDEP default pathways parameters.

3.3.3 Alternate Concentrations Limits for Loss-of-Control

Table 3.3 shows the soil concentrations corresponding to a dose of 100 mrem/y and are applicable for loss of control scenarios. The concentrations have been determined by dividing the

dose factors into the allowable 100 mrem/y. Again the concentrations for all NJDEP pathways (with default values) are provided in parentheses.

TABLE 3.3
DCGL(pCi/g) FOR LOSS OF CONTROL SCENARIO
BASED ON NJDEP DEFAULT ANALYSIS OF EXTERNAL RADIATION AND INHALATION PATHWAYS

Construction Type	Natural Decay Series	1 ft VE	5 ft VE	9 ft VE
0 ft of uncontaminated surface soil (USS)				
Basement	Thorium	16.8 (14.5)	12.9 (10.9)	10.2 (8.9)
	Uranium	24.3 (15.2)	18.5 (10.0)	14.5 (7.8)
Slab-on-Grade	Thorium	15.0 (13.5)	15.0 (12.4)	15.0 (12.4)
	Uranium	21.6 (15.0)	21.6 (10.8)	21.6 (9.5)
1 ft of uncontaminated surface soil (USS)				
Basement	Thorium	80.6 (59.7)	16.1 (13.5)	10.2 (8.9)
	Uranium	115.5 (44.4)	23.1 (11.6)	14.5 (7.8)
Slab-on-Grade	Thorium	52.2 (42.3)	23.9 (17.9)	23.9 (17.9)
	Uranium	74.0 (36.1)	34.1 (13.2)	34.1 (11.3)
2 ft of uncontaminated surface soil (USS)				
Basement	Thorium	80.6 (59.7)	16.1 (14.1)	11.6 (10.5)
	Uranium	115.5 (44.4)	23.1 (12.6)	16.6 (9.0)
Slab-on-Grade	Thorium	114.7 (76.0)	42.0 (30.0)	42.0 (30.0)
	Uranium	163.9 (49.3)	60.0 (18.5)	60.0 (14.9)
3 ft of uncontaminated surface soil (USS)				
Basement	Thorium	80.6 (70.1)	16.1 (14.9)	13.6 (12.7)
	Uranium	115.5 (56.3)	23.1 (13.8)	19.4 (10.7)
Slab-on-Grade	Thorium	130.4 (85.1)	65.7 (49.3)	65.7 (49.3)
	Uranium	186.6 (53.1)	94.0 (25.5)	94.0 (19.2)

Notes:
Natural series in equilibrium.
Number in brackets is concentration with 100 mrem/y based on all Pathways.
Uranium series includes U-235 decay series radionuclides at 5% of U-238 series.

4.0 SITE CHARACTERIZATION DATA

Site-specific characterization studies of the HMI site have been conducted, the most comprehensive of which is the Mine Tailings Radioactivity Assessment Plan (MTRAP) (CDM 1998). The MTRAP data provide information on estimated activity in borehole samples along with surface and downhole measurements of gamma radiation levels. These measurements are used to estimate the volume of materials that would exceed the site-specific DCGLs for potential site-specific options considered for this site.

4.1 RADIOLOGICAL CHARACTERIZATION STUDIES

Radionuclide concentrations can be measured using various laboratory and field methods. The concentrations of individual radionuclides can be measured in soil samples using laboratory methods that measure the energy and number of particles given off during radioactive decay. Field instrumentation is also available (e.g. field gamma spectroscopy) to quantify radionuclide concentrations; however, simple gamma radiation rate meters have proven effective as surrogates for radionuclide concentrations due to presence of radionuclides in the uranium and thorium decay series that produce an amount of gamma radiation that is easily and precisely measured by field instrumentation. Site-specific relationships can be developed between the count rate in these gamma radiation detectors and laboratory analyses of radionuclide concentrations in soil samples. This approach provides the opportunity of cost-effective, comprehensive and real-time estimates of radionuclide concentrations for natural uranium and thorium decay series that are in, or near, equilibrium.

4.2 EXISTING RADIOLOGICAL CHARACTERIZATION DATA

4.2.1 Pre-MTRAP Radiological Data

Historic radiological data collected for the site have previously been reviewed (SENES 1995). The data comprises gamma radiation surveys, including a grided survey of the Blue and Grey Areas, soil samples, and some water quality samples.

4.2.2 Prior Background Characterization

A background characterization study was conducted according to NUREG-5849 guidance as requested by NJDEP (RSI 1996). Ten initial locations were selected where surface gamma radiation levels were measured and soil samples were analyzed for Ra-226 and Th-232 activities. An additional 22 locations were sampled to meet the NUREG-5849 requirement that the mean value should be known within 20% of the mean value. The mean background concentrations reported from this study were 0.31 and 0.25 for U-238 and Th-232, respectively for a total

activity of 0.56 pCi/g (U-238 + Th-238). The mean gamma radiation levels on the surface were reported at 3 μR/h (2.84 μR/h prior to rounding).

Site characterization approaches have evolved substantially since that time, specifically, in the case where multiple radionuclides are naturally present, variable, and at levels comparable to the clean-up criteria. NJDEP has requested that NUREG-1575 (i.e. MARSSIM) be referred to develop background (letter to Picco received 30 December 1998). More recently, the NJDEP has stated that NUREG-1505 may be necessary in situations where background is variable and at levels comparable to the cleanup criteria.

4.3 MTRAP CHARACTERIZATION

A radiological characterization of the site condition in 1997 has been reported by Camp Dresser & McKee (CDM, 1998). The overall approach was to establish a grid of boreholes across the site with collection of soil samples at 1 foot depth increments. A calibration between gamma radiation measurements from a flux box and radionuclide concentrations from a sub-sample of the collected samples was developed and used to estimate the sum of U-238 (Ra-226) and Th-232 activities

Volumes of contaminated material were estimated based on downhole gamma radiation logging measurements and stratigraphic observations. An overall average activity concentration of 7 pCi/g for U-238 (Ra-226) plus Th-232 was reported.

4.3.1 Summary of MTRAP Measurements

A 200 foot by 200 foot grid was established over the 126 acre area of interest and gamma radiation levels were measured at each grid intersection using NaI detectors at a height of 1 m above the surface. The gamma radiation levels ranged between 6 and 305 μR/h with a mean gamma radiation level of 38 μR/h (CDM 1998).

Subsurface characterization comprised continuous soil sampling and down-hole gamma radiation measurements at 126 boreholes advanced at selected grid locations. Soil samples were collected and the total activity of U-238 (Ra-226) and Th-232 was estimated using the gamma flux box method. The average of all estimated concentrations was about 7 pCi/g; however, there was no specific reporting of estimated activity by area of concern. Profiles of gamma radiation levels and lithography by depth were provided for selected transects of the sites.

Table 4.1 summarizes the radionuclide levels measured in each area for the three main types of measurement; specifically, the surface gamma radiation measurements, the estimated (using the gamma box method) activity in borehole samples and the measured gamma radiation level down

the boreholes reported as counts per minute (cpm). The data were not electronically available at the time of this report and have been manually extracted by SENES from the MTRAP report. The table includes a summary of measured (by laboratory) activities; however, these samples tended to be selected from areas of higher levels of naturally occurring radionuclides and are, therefore, not representative of the overall pattern of activity in the AOCs.

TABLE 4.1
SUMMARY OF MTRAP RADIOLOGICAL MEASUREMENTS

Parameter	Number of Obs	Mean	Median	90th Perc.	Maximum
All MTRAP measurements					
Activity (Est.) pCi/g	941	7.0	6.7	6.7	100.2
Activity (Mea.) pCi/g	72	24.4	19.2	57.0	99.0
Gamma (Borehole.) cpm	1779	7907	3394	19594	21E4
Gamma (Surface) μR/h	820	40	26	94	305
Blue Area					
Activity (Est.) pCi/g	390	9.4	6.7	16.1	100.2
Activity (Mea.) pCi/g	45	29.5	23.7	59.0	99.0
Gamma (Borehole.) cpm	679	12168	6694	26618	21E4
Gamma (Surface) μR/h	268	71	69	121	200
Grey Area					
Activity (Est.) pCi/g	234	5.8	6.7	6.7	72.2
Activity (Mea.) pCi/g	16	18.0	14.8	39.0	67.0
Gamma (Borehole.) cpm	455	5216	1742	13667	138E3
Gamma (Surface) μR/h	236	32	24	54	305
Sand Pile					
Activity (Est.) pCi/g	107	2.9	2.0	6.7	6.7
Activity (Mea.) pCi/g	1	5.5	5.5	5.5	5.5
Gamma (Borehole.) cpm	178	10134	9817	13460	18125
Gamma (Surface) μR/h	19	38	34	60	86
Mill Vicinity					
Activity (Est.) pCi/g	208	5.8	6.7	6.7	25.4
Activity (Mea.) pCi/g	10	13.5	14.2	21.3	23.0
Gamma (Borehole.) cpm	457	3505	1687	8480	29317
Gamma (Surface.) μR/h	241	18	14	36	90

Figure 4.1 shows an overview of the MTRAP radiological data along with an outline of the AOCs. The figure shows the surface gamma radiation levels and the maximum estimated activity in each of the boreholes. It is visually apparent the highest surface gamma radiation levels and borehole activity occurs in the western half of the Blue Area.

FIGURE 4.1
MTRAP MEASUREMENTS

4.3.2 Comments on Methods Used in the MTRAP Program

CDM used a calibration curve relating gamma radiation levels measured from a sample of soil placed in a controlled geometry to the radionuclide concentrations measured using laboratory gamma spectroscopy. Not all radionuclides in the uranium and thorium decay series were measured and the relationship was based on the sum of activities of one radionuclide from the uranium series and one radionuclide from the thorium decay series. This implies an assumption of equilibrium conditions in the decay series which, as previously discussed, is appropriate for

the site. This approach, denoted as the "gamma box" method was used to characterize soil samples from homogeneous depth horizons in the boreholes. A number of samples with radionuclide analyses were used in developing the calibration curve and additional samples were analyzed in the laboratory for verification purposes.

The gamma box method is relatively imprecise for measurements at low levels of radionuclides; however, the gamma box method is useful for the screening level assessments of the extent and magnitude of radioactive materials and for assessing the feasibility of site-specific options. The downhole borehole gamma measurements provide a more precise characterization of radionuclide concentrations compared with the "gamma box" method since a much larger volume of soil and amount of radioactivity is being measured compared to the small volume in the "gamma box."

For this assessment, an estimate of this relationship has been developed based on soil horizons where the activity has been determined in the laboratory using gamma spectroscopy analysis and where downhole gamma radiation levels have been measured. From summarization of the MTRAP data, the average activity in these soil horizons was 25.4 pCi/g (U-238 + Th-232) and the average gamma radiation level from the borehole measurements was 27560 cpm. This implies an overall factor of 0.00092 pCi/g per cpm between borehole gamma radiation levels and activity concentration in the soil e.g.

$$\left(\frac{25.4\ pCi/g}{27560\ cpm}\right)$$

Note that use of this factor will overestimate activity levels at near background conditions due to the presence of naturally occurring potassium which typically contributes about 40% of the gamma radiation exposure rate from natural soils. For present purposes, we conservatively assume that natural potassium contributes 500 cpm to borehole gamma radiation levels. The predictive equation than becomes:

Total Activity = 0.00092 * (CPM –500)

The equation predicts a total (U-238+ Th-232) activity concentration of 1.4 pCi/g at a count rate of 2000 cpm.

4.4 ALTERNATIVE BACKGROUND CHARACTERIZATION

4.4.1 MTRAP Study

The MTRAP assessment noted that the existing site-specific background characterization study at that time reported a mean gamma exposure level of 3 μR/h, but a consultant at the time (Max

El Tawil) had noted that the background survey did not reflect areas with naturally occurring heavy mineral sands (CDM 1998). Surface gamma radiation surveys in un-mined areas known to contain heavy minerals ranged from 5 to 7 μR/h. Additional background measurements that were collected indicated surface gamma radiation levels of 4 to 5 μR/h in one undisturbed area with natural heavy minerals and about 2 μR/h in areas without heavy mineral content. Based on the larger survey considered by El Tawil, background gamma exposure rates in areas with heavy mineral content range up to 7 μR/h or more than 2.5 times the mean exposure rates (2.8 μR/h) in the original background study. This suggests that the original site-specific background study may have underestimated the activity concentration and a more appropriate estimate of background activity (U-238 + Th-232) might be about 1.5 pCi/g (i.e. 2.5 times 0.56 pCi/g).

The MTRAP assessment used a downhole gamma radiation level of 1500 to 2000 cpm to define the vertical extent of tailings implying that this was considered the background radiation level of sub-surface soils. Using the general relationship between borehole gamma radiation levels and measured activity in the MTRAP program, this would correspond to background activity concentrations in the range of 0.9 to 1.4 pCi/g. This range of concentrations is somewhat higher than the previous background characterization and generally consistent with a potential background concentration of 1.5 pCi/g based on the surface gamma radiation measurements.

4.4.2 Background Derived From Mineral Exploration

Mineral exploration activities included an extensive borehole program to catalogue naturally occurring mineral deposits on parts of the site. The concentrations were estimated by 5-foot depth increments, and a general relationship of increasing radioactivity with increasing heavy mineral fraction was discovered. Therefore, increasing TiO_2 concentration provides a basis for quantifying natural variability in Th-232 and Ra-226 concentrations.

A regression relationship was developed based on gamma spectroscopy of soil samples and corresponding TiO_2 concentrations (SENES 1995b). The data included downhole gamma radiation measurements ranging from 1007 cpm with 1.13% TiO_2 to 2197 cpm with 3.46% TiO_2 in type "E" soils corresponding roughly to an increasing of 500 cpm per %increase in TiO_2 above 1%. For the same content, gamma radiation levels tended to be higher in finer soils: for example, the gamma radiation level for a 1.82% TiO_2 in sample from "D" soil was 2462 cpm. These measurements indicated downhole gamma radiation levels ranging above 2000 cpm in undisturbed background locations. This level is comparable to that used to define the depth of tailings in this assessment.

Bulk Estimate of Mined Material

As a crude approximation, the heavy mineral fraction at the HMI site contains about 50% TiO_2 so that the relationship with gamma radiation is about 250 cpm per % heavy minerals (i.e. heavy minerals at the site are approximately 50% TiO_2). The original ore dredged/mined from the site was nominally 5% heavy minerals; thereby implying an average gamma radiation level on the order of 3000 cpm for these materials (2000 cpm (background) + 5 x 250 cpm). Using the relationship in the MTRAP data, the average background activity concentration in the dredged/mined materials was on the order of 2 pCi/g (U-238 + Th-232). However, the use of this approach to background characterization may not be preferable since most of the radioactivity was originally located at a depth of 80 feet below the surface.

It is of note that the gamma radiation in the natural deposit previously located at the bottom of the present day lakes would be about 25000 cpm corresponding to pure heavy minerals (e.g. 250 cpm per % times 100%).

4.4.3 Formal Background Characterization

NJDEP has suggested that a formal background study based on MARSSIM technology may be required for this site. The MTRAP assessment was approved by NJDEP before the development of MARSSIM and, given the thorough understanding of the radioactivity to heavy mineral fraction ratio and their natural stability, the thorough process history knowledge, and the relatively homogeneous nature of the disposition in the soils in the various defined areas of the site, such a detailed and expensive site characterization appears unnecessary and perhaps would impose an unfair "back-fitting" requirement.

In our opinion, the existing characterization is adequate for planning the remediation approaches. A MARSSIM-type survey would be conducted as part of the verification survey once remediation has been completed.

4.5 VOLUME OF MATERIAL REQUIRING EXCAVATION

The volume of contamination depends on background concentrations developed for the site and the intended uses. In this section, we develop volume estimates for a range of background concentrations and for various DCGLs considered for the property.

4.5.1 DCGLs and Background Concentrations

The MTRAP characterization program was based on estimates of total (i.e. Th-232 + U-238) activity in the soils and measurements of gamma radiation levels. These measurements do not

discriminate between Th-232 and U-238 or the individual radionuclides within the decay series. As discussed earlier, it has been considered reasonable to expect that radionuclides within the natural uranium and natural thorium decay series will have similar (i.e. in equilibrium), activity levels.

Examination of the site-specific DCGLs in the preceding chapter suggests that the DCGLs for uranium are generally higher than those for the thorium series and, hence, a DCGL for combined uranium and thorium set equal to the thorium DCGL will be conservative (i.e. protective of health) while removing the need to assess individual series concentrations. **As a result, a single DCGL for total activity is used in this report and is set equal to the DCGL for the thorium series.**

Background Concentration

It is likely that the original site-specific background concentrations of 0.56 pCi/g (U-238 + Th-232) underestimates the actual natural background concentration for locations where heavy minerals have been mined. A formal survey following current protocols has not yet been conducted to develop a more realistic (i.e. higher) background characterization. A more formal site-specific background characterization would be expected to support a background activity concentration on the order of 1.5 pCi/g (U-238 + Th-232) based on a simple analyses of gamma radiation levels measured on undisturbed areas of the HMI site containing heavy minerals. A background value of 1.5 pCi/g has been used for consideration of remediation options in this report.

At this time, a formal study to more fully define background is not necessary but could be considered if the potential cost implications of remediating what might actually be natural background levels is found to be excessive in subsequent engineering and cost studies.

DCGLs for Consideration

The "fail-safe" limiting concentration for the site is based on a 100 mrem/y dose under loss of control scenario. We consider the most pessimistic scenario to be where a basement home is built in a 9 ft (effectively infinite) thickness of elevated material with no uncontaminated surface soil. The Th-232 concentration corresponding to 100 mrem/y would be 10.2 pCi/g (see Table 3.3). This value when used for total activity would be a conservative (i.e. protective) DCGL for total activity since the U-238 DCGL for this scenario would be 14.5 pCi/g.

The DCGLs corresponding to the 15 mrem/a dose criterion are dependent on institutional (e.g. land use) controls established for the relevant portions of the site and the vertical extent of elevated concentrations.

The intended use for the development area of the site is for retirement residences and the goal is to meet NJDEP criteria for unrestricted release in the development area. For the receiving area of the site where the TENORM material would be placed and mixed, restrictions enforced by the State of New Jersey for "parkland only" status in perpetuity will be considered as an institutional control. The DCGLs for total incremental activity of Th-232 and U-238 are then given by Table 4.2 for 5 ft and 9ft vertical extent with no uncontaminated surface soil (USS). The DCGL for recreational use are based on NJDEP default values and an occupancy factor of 50 h/y (Yu *et al.* 2001). The dose factor for recreational uses is 0.106 mrem/y per pCi/g.

TABLE 4.2
REMEDIATION DCGLS

Restriction	5 ft (VE)	9 ft (VE)
Loss-of-Control (at consolidation site)	12.9	10.2
Recreational Use (at consolidation site)	141	141
Unrestricted Use (at development site)	1.9	1.5

The table indicates that the incremental concentration over a vertical extent of 5 feet can not exceed 12.9 pCi/g in order to meet the 100 mrem/y "fail-safe" criterion for loss-of-control and must be 1.9 pCi/g to meet the unrestricted release criterion. Five feet is the approximate depth of material after remediation.

4.5.2 Estimated Volumes

Note: *This section should not be interpreted as a formal estimate of volumes intended to support a detailed engineering and cost assessment but rather a preliminary estimate of potential volumes of soil and tailings to be remediated. These preliminary estimates are provided to assist in the preliminary evaluation of the feasibility of various remedial approaches.*

The MTRAP data has been analyzed to determine the volume of material that exceeds the DCGLs for the options considered for the site. The volumes have been estimated using the downhole data to determine the depth of material above the DCGL, the volume of this material and the average activity in the material.

In the MTRAP assessment, the vertical extent of contamination was based on the depth where down-hole gamma radiation levels were in the range of 1,500 to 2,000 cpm (CDM, 1998). Using this cutoff level of (about) 2000 cpm, based on an estimate of site-specific background radiation levels, the volumes of above-background radioactivity were calculated. For the site-specific options discussed in this report, it is not the volume of material that is "above background"

which is of concern; rather, *it is the volume of material that exceeds "background" plus the DCGL.* In order to estimate these volumes using the downhole gamma radiation level it is necessary to relate activity concentrations to downhole gamma radiation levels.

The volumes of interest are calculated based on the sum of background and DCGL activity. Using the factor of 0.00092 pCi/g per cpm previously described in this report, the gamma radiation levels corresponding to activity concentrations of interest can be calculated. Table 4.3 indicates that the borehole gamma radiation levels would vary from 4196 to 16152 cpm for the dose scenario considered for the site.

TABLE 4.3
CALCULATED BOREHOLE GAMMA RADIATION LEVELS (cpm) CORRESPONDING TO REMEDIATION GOALS

DCGL (U-238 + Th-232)	Borehole Gamma Radiation Level (cpm)
1.9 (unrestricted release) for development area	4196
12.9 (loss of control) for consolidation area	16152

Notes:
Based on 5 ft Vertical Extent and 1.5 pCi/g background level.
DCGL is incremental activity above background
Borehole gamma radiation level includes background contribution.

The volumes requiring remediation for each DCGLs is based on the deepest depth in a borehole where the corresponding gamma radiation level is exceeded. Note that, in some cases, the radioactivity in a soil horizon above this level may be lower than the corresponding gamma radiation level. The depth from each borehole is then used to estimate the volume in each area of concern based on interpolation of depths from the boreholes.

Table 4.4 summarizes these volumes including the volume of material where the downhole gamma radiation level exceeds 2000 cpm for comparison against the volume estimates from the MTRAP assessment. The total volume of "above-background" material is estimated at about 930,000 yd^3 which is comparable to the MTRAP estimate of 1 million cubic yards. The volume of material that exceeds a DCGL for 5 ft vertical extent (1.9 pCi/g above background) is 690,000 yd^3 with a bounding estimate of about 310,000 yd^3 for the "fail-safe" loss-of-control scenario.

TABLE 4.4
ESTIMATED REMEDIATION VOLUMES

Area of Concern	Acreage (acres)	Average Depth (ft)	Volume (yd^3)	Average Activity (pCi/g)
Clean-up to Background (1.5 pCi/g)				
Blue Area	41.2	6.3	420,069	10.9
Grey Area	43.7	3.1	216,934	6.8
Sand Pile	4.8	15.4	119,850	8.8
Mill Vicinity	38.2	2.8	173,003	4.6
TOTAL	127.9	4.5	929,856	7.5
Lost of Control (100 mrem/y or 12.9 pCi/g)				
Blue Area	36.4	3.1	182,458	21.7
Grey Area	41.6	0.8	55,990	22.6
Sand Pile	4.8	4.1	31,615	11.0
Mill Vicinity	22.4	1.2	43,019	18.8
TOTAL	105.2	1.8	313,082	21.2
Unrestricted Release (1.9 pCi/g above background)				
Blue Area	40.9	5.1	335,220	13.7
Grey Area	43.7	2.1	149,441	9.3
Sand Pile	4.8	14.7	114,655	9.3
Mill Vicinity	28.1	2.0	91,243	8.3
TOTAL	117.5	3.6	690,558	10.6

Note:
Activity estimates include background concentrations

5.0 SITE-SPECIFIC OPTIONS

This chapter describes remediation approaches considered for the Heritage site and a qualitative evaluation of the options. The approaches are technically feasible and meet NJDEP dose criteria; however the engineering and other costs for the approaches are not known at this time.

5.1 GOALS

The goal of remediation is to reduce the levels of naturally occurring radionuclides at the site in a cost-effective manner that is protective of human health during remediation and into the future. After remediation, the site will meet NJDEP release criteria of 15 mrem/y (100 mrem/y for loss-of-control), less than 3 pCi/L incremental indoor radon and NJDEP groundwater criteria.

The intended use on the development area of the site is residential with open space uses on other areas of the HMI site. A goal is to provide site conditions suitable for these uses with no dependency on engineering controls and only minimal dependence on State imposed institutional controls.

5.2 POTENTIAL SITE-SPECIFIC OPTIONS

Two potential site-specific options have been considered for TENORM materials that exceed the DCGL for unrestricted release. Both options would leave the development area of the site suitable for unrestricted property use. These are:

- "Consolidation": Mixing and consolidating the materials containing slightly elevated levels of radionuclides onto another area of the site leaving the original location in a condition suitable for unrestricted release. These lands would be owned by one or more government entities which will have power to enforce the land use restrictions. State enforced restrictions on use would prevent construction in the consolidation area and concentrations in the material would be such that loss of State enforced institutional control would result in doses less than (<) 100 mrem/y.

- "Restoration": The material with slightly elevated levels of radionuclides would be placed on the bottom of the lakes created by dredging/mining of the original ore. This approach is consistent with returning the site to its original condition since the majority of the heavy minerals were located in a high-grade vein of ore at the bottom of these man-made lakes. The original site location would have been suitable for unrestricted property use.

5.3 AREAS AVAILABLE FOR SITE-SPECIFIC OPTIONS

The intended use of the development area is for residential slab-on-grade development. The site-specific options require that the DCGLs and dose criteria are met. Table 5.1 conceptualizes the approaches, target activity concentrations and institutional and engineering controls required for each option.

TABLE 5.1
CONCEPTUAL APPROACH TO REMEDIATION

	Intended Development Area (AOCs)	Receiving Area
Consolidation	Meets unrestricted release (1.9 pCi/g above background)	Meet dose criteria through institutional control and meet loss of control criteria (e.g. <12.9 pCi/g above background)
Restoration	Meets unrestricted release (1.9 pCi/g above background)	No controls : a return to original site condition

The receiving area across the railway tracks from the processing facility (shown schematically on Figure 2.1) is considered a potential consolidation site where materials with slightly elevated radionuclide concentrations could be consolidated and then subjected to State imposed institutional controls restricting land use to recreational open space. For example, the elevated material could be removed from the AOCs to concentrations levels appropriate for unrestricted release (i.e. 1.9 pCi/g above background). The 690,000 yd^3 of elevated material having an average concentration of 10.9 pCi/g activity (including 1.5 pCi/g background) would be consolidated (see Table 4.4 for volume and activity estimates). The concentration in the consolidated material would be lower than the concentration corresponding to 100 mrem/y in a loss-of-control scenario. Doses under the recreational use scenario would be considerably lower, 1 mrem/y, than the 15 mrem/y criterion.

The elevated material could be removed from the AOCs and placed in the bottom of the lakes where the heavy minerals were originally removed. The larger lake is on the order of 88 acres in area. Placement of all 690,000 yd^3 of material would result in a layer that was about 5 ft thick at the bottom of the 80 ft deep lake leaving a nominal water cover of about 75 feet.

5.4 EVALUATION OF SITE-SPECIFIC OPTIONS

This section outlines the considerations for evaluating the two site-specific options.

5.4.1 Technical Feasibility

The technical feasibility of the site-specific options relates to the effectiveness in meeting NJDEP unrestricted use criteria, the applicability to site conditions, and the complexity of the approach. Locations are available at the HMI site to address the TENORM material, but the complexity of the approach and the effectiveness of the options will vary.

Although the materials are relatively homogenous with respect to the source and composition, the depth and amount of mixing with sands with lower levels of naturally occurring radionuclides varies somewhat across the site. This means that options involving consolidation or mixing (under the TENORM approach) would need to consider the concentrations at a scale of individual residential lot size. While moving or mixing of soil inherently will act to average out these variations, efforts would be required during remediation and verification sampling to ensure the design concentrations were met.

In principle, placement of the TENORM material back into the bottom of the lakes would be the simplest option involving the re-pulping of the material and using a slurry approach to pump and place the materials back into the lake. This would be, in effect, a reversal of the mining procedure and would provide a significant degree of mixing.

5.4.2 Radiological Considerations

Radiological implications from radon and groundwater concerns are rendered irrelevant due to the chemical and physical characteristics of the heavy minerals. Radiological doses arise from external gamma radiation exposures and inhalation.

The radiological implications of simply mixing the materials and consolidating based on a TENORM strategy would result in an estimated dose of 1 mrem/y, which is substantially below the 15 mrem/y dose criteria under the recreational use scenario while limiting doses to 100 mrem/y under a loss-of-control scenario.

Placement of all the TENORM material into the bottom of lakes would reduce the incremental radiation dose to zero since the radioactivity in the TENORM material would be returned to its original place in nature. There would be no external gamma radiation from this material or inhalation due to its isolation, and the material is insoluble so no radioactive dose from groundwater or the ingestion pathway would arise from this option. This should not be considered an engineering control or institutional control since the material has been returned to

its original place in nature essentially in the same form and with a lower concentration of heavy minerals, including monazite and its contained naturally occurring radionuclides. The levels of naturally occurring radionuclides in this location will actually be lower than concentrations present prior to dredging/mining activities.

5.4.3 Regulatory and Public Acceptance

These site-specific options are desirable in that the material is TENORM and was not brought onto the site.

There may be some resistance to the option of returning the material to the bottom of the lakes where it originated due to sensitivity of the public regarding perceived groundwater contamination. The insolubility of these materials and lack of elevated radionuclide concentrations in groundwater even though heavy minerals are present in the local area indicate that this is not a scientific or technical issue.

5.4.4 Costs

Based on our assessment, both site-specific options discussed above are likely able to the meet the NJDEP criteria; however, the cost implications of these options may vary substantially. In order to arrive at a final proposal, it is recommended that engineering cost estimates be developed for each site-specific option, including the costs for characterization and final status survey requirements.

5.5 SUMMARY

Table 5.2 summarizes the two site-specific options. The restoration option involving the placement of the TENORM materials at the bottom of the lakes appears to be the preferred approach from a radiological dose, a technical feasibility, and a potential site impact standpoint.

TABLE 5.2
COMPARISON OF REMEDIATION OPTIONS

	Controls Required	Radiation Dose	Site Impact
Consolidation	Institutional Control (recreational use)	<15 mrem/a	Only Institutional controls for Open Space Area
Restoration (Placement in Lake Bottom)	None	Nil	Nil

6.0 DISCUSSION/CONCLUSIONS/RECOMMENDATIONS

6.1 SUMMARY OF PRELIMINARY INVESTIGATIONS

The materials containing slightly elevated levels of naturally occurring radionuclides at the HMI site is TENORM arising from the dredging/mining and processing of heavy mineral sands containing naturally occurring radionuclides. The material has physical and chemical characteristics that are site-specific relative to consideration for DCGLs and site-specific options.

- The U-238 and Th-232 decay series are considered to be in secular equilibrium due to the insolubility of heavy minerals and the lack of chemical processes during mining activities.

- Radon emanation from heavy minerals is much lower than from ordinary materials. With a conservative estimate of 90% lower, a site-specific relationship of 0.15 pC/L per pCi/g can be used rather than the default NJDEP value of 1.5 pCi/L per pCi/g. Radon is not a concern when addressing the TENORM material at the HMI site.

Site-specific DCGLs were calculated for this site based on the physical and chemical properties of heavy minerals; specifically, the insolubility of heavy minerals in natural environments.

- Doses from the groundwater and ingestion pathways are rendered irrelevant based on the insolubility of heavy minerals (a site-specific factor).

- A DCGL for total (U-238 plus Th-232) activity can be used for this site with the DCGL based on Th-232 activity. This is conservative since U-238 has a higher, albeit similar, DCGL compared with Th-232 and facilitates the use of total activity for planning and implementation of a site-specific option.

Preliminary volume and activity estimates have been determined using downhole gamma radiation readings measured as part of the MTRAP program rather than using the gamma flux box measurements. Using these volume estimates, two general site-specific options were considered including: i) above-ground consolidation using institutional controls; and, ii) restoration through placement in the lake bottom where the majority of the heavy mineral materials were originally located.

A qualitative assessment identifies placement in the bottom of the lakes as the preferred approach due to lower radiological dose, no requirement for institutional or engineering controls and lack of technical complexity.

6.2 STEPS FORWARD

The unit costs for the above-mentioned site-specific options should be evaluated in order to compare their cost-effectiveness and to determine the sensitivity of cost to background levels. For example, options such as placement of elevated material in the lake bottom may be less sensitive to background levels than options involving consolidation and mixing.

The existing site-specific background characterization likely underestimates background radioactivity levels that are appropriate for this site and a value of 1.5 pCi/g (U-238 plus Th-232) has been used in this report.

Final verification and, potentially, refinements to these site-specific options may require a MARSSIM-like approach to reflect the natural variation in radioactivity present at sites, like the HMI site, that contain heavy minerals.

The relationship between downhole gamma radiation levels and activity concentrations should be formalized since this provides a more precise estimate of *in situ*, and present, activity concentrations than the gamma box method.

Final verification studies would likely be designed with a MARSSIM-like approach to provide confidence in a cost-effective and scientifically defensible manner that the proposed site-specific option(s) actually accomplishes the intended objective.

REFERENCES

Camp Dresser & McKee (CDM) 1997 *ASARCO/HMI Route 70, Mile Marker 41 Site Mine Tailings Radiological Assessment Plan (MTRAP) Correlation of Field Testing Measurements to Analytical Soil Results*, Letter to John F. Lord, 7 August 2002.

Harrington T.R. 1993. *A Study of Potential Radiation Doses Arising from a Proposed Mineral Sand Mine and Processing Plant in Victoria.* Radiation Protection in Australia 11(4).

Kerrigan G.C., O'Connor B.H. 1990. *Evaluation of Th Series Disequilibrium in Western Australian Monazite.* Health Physics 58(2):157-63, February.

Koperski J. 1993. *Radiation Protection in the Mining and Milling of Mineral Sands.* Radiation Protection in Australia 11(2).

New Jersey Department of Environmental Protection (NJDEP) 2000. *Subchapter 12 Remediation Standards for Radioactive Materials.*

New Jersey Department of Environmental Protection (NJDEP) 1997. *ASARCO/Heritage Minerals Inc. Site Route 70, Mile Marker 41, Manchester Township, Ocean County Letter Report Date August 7th 1997 Correlation of Field Testing Measurements to Analytical Soil Results.* Letter to Steven Picco from Vicky M. Galofre, Undated, Received 16 December 1997. New Jersey.

Nuclear Regulatory Commission (NRC) 1993. *Site Decommissioning Management Plan Heritage Minerals*, pp. A51-53 NUREG-1444.

Paschoa A.S., Eisenbud M., and Godoy J.M. 1993. *Radium availability in monazite sands from two distinct sites.* Radiation Protection in Australia Vol. 11, No.4.

Radiation Sciences Inc. (RSI) 1996. *Report of Site Background.* Prepared for Heritage Minerals, July.

SENES Consultants Limited 1995a. *Review of Radiological Data: Heritage Minerals Site, Manchester Twp, New Jersey* Prepared for Heritage Minerals Inc, February.

SENES Consultants Limited 1995b. *Radon Flux Rate Mapping Procedure* Prepared for Heritage Minerals Inc, November.

Yu, C., A.J. Zielen, J. J. Cheng, D.J. lePoire, E. Gnanapragasam, S. Kamboj, J. Arnish, A. Wallo III, W.A. Williams, and H. Peterson 2001. *User's Manual for RESRAD Version 6*, ANL/EAD-4, July, NUREG-1444.

APPENDIX A

SUPPORTING QUALIFICATIONS

DOUGLAS B. CHAMBERS

Vice-President, Director of Radioactivity and Risk Studies

EDUCATION

B.Sc. (Honours), Physics, 1968, University of Waterloo (University of Waterloo Tuition Scholarship)
Ph.D., Physics, 1973, McMaster University (National Research Council Science Scholarship)
Two Sessions at the Advanced School for Statistical Mechanics and Thermodynamics, University of Texas, Austin, 1970 and 1971
Air Pollution Diffusion, U.S. EPA, Research Triangle Park, 1974
Annual Health Physics Course, Chalk River Nuclear Laboratories, 1974
Observations on Human Populations, School of Hygiene, University of Toronto, 1979

PROFESSIONAL AFFILIATIONS

Advisory Committee on Radiation Protection (1993 to 2002 - committee advises the Canadian Nuclear Safety Commission on matters concerning radiation protection)
American Nuclear Society
Canadian Standards Association, Member of Technical Committee on Environmental Radiation Protection (1978 to 1994, Chairman 1987 to 1994)
Canadian Standards Association, Member of Technical Committee on Risk Analysis (1989 to present)
Canadian Radiation Protection Association
Health Physics Society (U.S.)
Society for Risk Analysis (U.S.)
U.S. National Council on Radiation Protection and Measurements, Scientific Committee 85 on Risk of Lung Cancer from Radon (1991 to date)
United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), Member 1998 to date, Canadian delegation
Consultant to UNSCEAR for preparation of "Sources-to-Effect Assessment of Radon in Homes and Workplaces".

AWARDS

1997 W.B. Lewis Award (Canadian Nuclear Association) for achievements in environmental radioactivity.

2002 Health Physics Society.
Morgan Lecturer
"Perspectives on Radioactive Waste Management in Canada. Joint Midyear Meeting. Orlando, February 2002.

EXPERIENCE

1980 to date - SENES Consultants Limited
Vice-President and Director of Risk and Radioactivity Studies. Technical responsibilities include management and technical direction of multi-disciplinary studies including: human health risk assessments; radioactivity exposure evaluations; environment impact assessments; environmental pathways and dose assessments; air dispersion modelling studies of radon and dense/reactive gases; ecological risk assessments; mine waste management; geochemical modelling assessments; low-level radioactive waste management; and risk (cost) - benefit analyses.

Dr. Chambers has contributed to the development of, and made extensive use of the methods of uncertainty analysis for: exposure pathways analysis; dose reconstruction and epidemiological investigations; risk assessments; and application of environmental statistics. While at SENES, Dr. Chambers has directed or contributed to more than 300 projects, examples of which are given below.

Human Health Risk Assessment - Numerous studies including: risks from exposure to radon; investigations into harmonization of cancer and non-cancer risk; integrating quality of life issues in cost-benefit analyses; studies of the effect of uncertainty in exposure (dose) on the feasibility of epidemiological investigations, pharmacokinetic modelling and toxicological assessments of uranium, arsenic and other toxins; and evaluation of the risks associated with nickel in soils at contaminated sites proximate to nickel production facilities.

Risk assessments performed under Dr. Chambers' direction include evaluation of risks from: naturally occurring radioactivity in phosphogypsum arising from use in agriculture and road construction; radioactivity, and various metals in drinking water; reuse of industrial contaminated sites; incineration of municipal wastes and accidental release of chlorine from waste water treatment facilities. Other projects include: LNG storage facility; blood mercury levels and water level regulation in respect to low-head hydro projects; release of volatile organics from waste water treatment plant; risks for alternative uses of sewage sludge; and exposure to fugitive dust emissions from mining, municipal, radioactive and hazardous waste management activities.

Ecological Risk Assessment - Dr. Chambers has played a key role in the development of ecological risk assessment methodologies for mining regions in northern Saskatchewan and northern Ontario, and in support of decontamination planning for contaminated industrial sites. Dr. Chambers also completed an ecological risk assessment for the use of slag from refining operations as construction fill. He has directed numerous risk assessments for industrial contaminated sites.

Environmental Assessment – Numerous, assessments including: the preparation of an environmental impact statement for the decommissioning of uranium tailings facilities in Ontario and northern Saskatchewan, the United States and elsewhere; and a risk (cost) - benefit analysis for the reclamation of an *in situ* leach property in Texas. Dr. Chambers has also contributed to environmental assessments of nuclear power plants, thermal power plants and other industrial and mining facilities.

Facility Risk Assessment – Dr. Chambers has been involved in numerous facility risk assessments involving petrochemicals, ammonia, uranium hexafluroide, and chlorine amongst others. He has supervised a number of transportation risk studies involving petrochemicals, acids, radioactive waste, sludge and ore slurry. He has also been involved in a health and safety risk analysis for oxygen and nitrogen pipelines. These projects have been conducted in Ontario, British Columbia, Saskatchewan, South Africa and Trinidad.

Geochemical Modelling and Assessment - Dr. Chambers is active in the development and application of geochemical models for evaluation of management options for mine waste rock and tailings. He was a senior scientist in a multi-disciplinary study team assisting the Federal German Environment Ministry with the decommissioning of uranium mining and processing sites in Saxonia and Thüringia, where geochemical modelling was employed to perform a comparative evaluation of rehabilitation options for multiple surface waste rock heaps, including evaluation of specific criteria for relocation of waste rock to a large open pit mine, and geochemical simulation of the backfilled pit as well as the flooding of the entire mining area. Other geochemical assessments include evaluation of alternatives for reducing acid generation of mine waste heaps in South Africa.

Radioactivity - Director or senior health physics advisor for numerous studies pertaining to radiation protection including: dose reconstruction and epidemiologic analyses of persons exposed to elevated radon progeny concentrations including residents of Port Hope Ontario and uranium miners of Beaverlodge, Port Radium and Colorado Plateau; reconstruction of environmental exposures and doses from radioactive contaminated sites, decommissioning of uranium and thorium facilities; review of thorium metabolism data; and uranium biokinetic models; development of decommissioning criteria and guidelines; assessment of the potential risks from naturally occurring radioactivity (NORM);dose assessment and the development of health and safety practices for uranium mine workers; and the application of the ALARA optimization principal.

Remedial Actions and Decommissioning - Directed and participated in numerous decommissioning and remedial action programs for NORM (naturally occurring radioactive material) wastes and low-level radioactive waste (LLRW) management sites, uranium mining facilities in Canada, United States and overseas. Dr. Chambers directed conceptual design studies for disposal of LLRW in near-surface facilities and engineered underground caverns. He also directed a study to investigate the technical and economic feasibility of a commercial LLRW facility in Canada.

Air Quality Assessment - Provided technical direction to atmospheric dispersion studies involving dense/reactive gases such as ammonia, chlorine, anhydrous hydrogen fluoride and N_2/O_2 and uranium hexafluoride releases. Dr. Chambers developed a detailed physical/chemical model for the release, atmospheric transport and deposition of uranium hexafluoride for an accident at a uranium hexafluoride facility in Gore Oklahoma. He has carried out numerous site-specific modelling studies of thermal power stations, numerical air quality modelling for complex terrain, calibration/verification studies, and development of long-range transport models.

1973-1980 - James F. MacLaren Limited

General Manager, Nuclear Projects Division from 1977 to 1980. Responsible for the development of the firm's capabilities in environmental radioactivity and radiation protection. Project Manager for the Air Environment Division from 1973 to 1977.

Environmental specialist on matters pertaining to the air environment and/or radioactivity on numerous environmental impact assessments across Canada and internationally.

Specialist input to the development, implementation and interpretation of results from air quality and meteorological surveys, air dispersion analyses and noise assessments at several types of industrial projects at locations across Canada. Developed a meteorological control system for large oil fired power plant in New Brunswick.

Project scientists for the development of national inventory of sources, emissions and environmental fate of mercury, lead and beryllium and asbestos.

TECHNICAL PAPERS AND PRESENTATIONS

More than 100 technical papers, reports publications and presentations (list available upon request). He has also presented seminars and workshops on a variety of topics, in Canada, the United States, Europe, South America and Africa.

RONALD H. STAGER

Senior Environmental Statistician/Engineer

Education

M.Math, Statistics, 1987, University of Waterloo
B.Sc.(Eng), Agricultural Engineering, 1979,
University of Guelph

Member of Professional Engineers of Ontario

Experience

1989-date - SENES Consultants Limited

Senior Environmental engineer and statistician specializing in environmental statistics, risk assessment, radiation studies, solid waste quantification and characterization, and dispersion modelling.

Environmental Statistics - Provides technical advice on statistical analysis and database management for a large variety of environmental studies. Major contributor to several projects requiring specialized statistical analyses of environmental data. Provides clients and professional journals with scientific peer review for environmental sampling plans, statistical methodology, and data quality.

Development and testing of statistical methods for predicting source strength and spatial location of contaminants using non-intrusive measurements for an ongoing internationally-funded scientific program.

Performed multivariate analyses on several environmental data sets including precipitation chemistry, radioactivity, soil sampling of polyaromatic hydrocarbons, background surface water quality, effluent discharges, and solid waste composition data. Fit nonlinear statistical leachate models to test cell data.

Managed and analyzed relational databases with more than 100,000 records and analyzed datasets with more than one million observations. Modified geographic information system (GIS) data files for enhanced graphical presentation. Applied GIS methodology and geostatistical techniques to risk assessments and site characterizations. Developed spatial statistics approaches for detection of small elevations above temporally and spatially variable background levels.

Produced probability distributions for use in probabilistic analyses. Acquired data, reviewed data quality, selected empirical models, and provided mathematical fits to data. Developed and enhanced methodologies for the incorporation of below detection limit observations.

Risk Assessment - Programmed computer models to predict health effects resulting from exposure to biological microbes, chemicals and radionuclides. Developed and evaluated bio-kinetic models to relate excretion to likely intake of contaminants. Developed life table models to quantify the social and health impacts of risk.

Developed a computerized interface between air dispersion models and database files containing source characteristics, geographic attributes, population data, emission profiles and meteorological data and incorporate pathways algorithms to estimate dose and risk.

Radiological Characterization and Remediation

Designed, implemented and interpreted radiological characterization programs in support of remediation plans for properties contaminated with radioactivity um. These programs used automated collection of gamma radiation data incorporating GPS-based systems with database management and automated analysis and mapping using GIS (Arcview) software. Designed remediation programs and verification surveys.

Provided comments and assessed implications of draft Multi-agency Radiation Survey and Site Investigation Manual (MARSSIM) for a mining association and advised private companies on implementation strategies. Developed statistical methods to improve the detection limits for measurement of radon, detection of discrete and diffuse sources of contamination and an automated system to separate soils on the basis of radiological contamination levels.

Reviewed occupational exposure measurements to assess the implications of new regulations on uranium fuel cycle operations and lead researcher for retrospective analyses of exposures for a major epidemiological study. Provided external review of environmental radiation monitoring programs. Conducted pathways modelling for development of allowable releases from nuclear facilities.

Solid Waste Characterization and Quantification - Major contributor to a study of waste generated in a major metropolitan municipality. This project involved a statistical sample selection from defined sectors of waste generation and the projection of sample results to totals for the municipality. Waste generation rates for more than 20 sectors and more than 40 types of waste were calculated.

Participant in studies of packaging wastes, paper wastes and solid waste incineration. Investigated and compared methodologies of quantification and characterization of solid waste with respect to monitoring compliance with reduction guidelines.

Dispersion Modelling - Participated in several studies to model the effluent plumes arising from releases to receiving waters. These projects included both river and lake discharges from municipal and mining effluent

treatment facilities. Assessed the compliance of modelled plumes with respect to water quality objectives for the local jurisdiction. Provided conceptual design on the placement and outlet configuration for proposed developments. Assessed the assimilative capacity of receiving waters for a number of projects.

Conducted sensitivity analyses on the effects of uncertainty in emission characteristics and meteorological conditions on predicted concentrations from air dispersion models. Performed probabilistic analyses to estimate deposition arising from an accidental release. Related predicted airborne deposition patterns to observed soil concentrations.

1987-1989 - ACN Nielsen Company of Canada

Research statistician participating in electronic measurement of television viewing. Responsible for the selection and maintenance of a national sample of households, the calculation of universe estimates, and statistical analyses. Specific duties included; supervision of enumeration and recruitment procedures utilized by field staff, documentation of methodologies for audit requirements, presentation of survey techniques to industry technical committees and field personnel in information and training seminars, and liaison with Statistics Canada for acquisition of electronic data from census, household facilities, and labor force surveys in raw form as well as special analyses.

1983 - Coquitlam River Salmonid Enhancement Project

Provided engineering and supervisory support for an enhancement program on a depleted salmonid river system. Consultation with governmental experts and project team members included investigation and recommendations for control of sediment pollution sources; hydrological characterization of river system; design and supervision of habitat enhancements through flow control structures and placement of gravel for spawning beds; and supervision of the fabrication and operation of traps for biological sampling of salmonid populations.

1981-1982 - Canadian Bio Resources Engineering

Engineer-in-Training participating in environmental studies, water and sewer services, soil and drainage studies, and computer analyses.

Investigated the effects of construction of the proposed B.C. Hydro Site C dam on downstream water quality. Collected meteorological data for the site, programmed a computer model and conducted a sensitivity analysis on the effect of reservoir operation and meteorological parameters. Validated the model with pre- and post-construction data from a similar existing reservoir.

Participant in a study of the transport of diffuse source contaminants in the Okanagan Basin. Data on the depth of aquifers and soil types in study area were collected and a complete survey of agricultural, municipal, and industrial sources of contaminants in the basin was performed. A computer model was developed to predict the quantity of contaminants reaching receiving waters. Sensitivity analyses, model validation, and documentation were also completed.

Design and supervision of water supply and sewer services. Prepared innovative site-specific designs in order to comply with environmental concerns including constructed septic fields and peak-averaging systems. Managed projects requiring design specifications, permit compliance, tendering of bids, and supervision of work. Designed and applied for permits for the modification of natural habitat for the development of recreational areas. Designed drainage and soil placement for playing fields.

1980 - Schlumberger of Canada Limited

Junior Engineer responsible for maintenance and operation of data logging equipment in the petroleum industry in northwestern Alberta. Interpreted radioactivity and sonic well logs as well as performed production services.

Technical Papers and Presentations

Author of journal articles, technical papers and presentations on development of statistical methodology for characterization studies, risk from occupational exposures, data quality improvement, and the effect of uncertainty on epidemiological studies.

December 2002

SENES Consultants Limited

SELECTED RADIOACTIVITY EXPERIENCE

SENES, an acronym for Specialists in Energy, Nuclear and Environmental Sciences, is a wholly Canadian-owned company incorporated in Ontario in 1980. SENES provides leading-edge environmental services for industrial, commercial, governmental, and public interest groups on a broad spectrum of projects. Since formation in 1980, SENES has participated in over 3,000 projects throughout North America, as well as in the Caribbean, South America, Australia, Asia, Africa and Europe. SENES has its main office in the Greater Toronto Area (Richmond Hill) with branch offices in Ottawa, Ontario and Vancouver, British Columbia. SENES has established four other companies including: Decommissioning Consulting Services Limited in Richmond Hill; SENES Oak Ridge Inc., Center for Risk Analysis in Tennessee, U.S.A.; SENES Chile; and SENES India - to provide additional services in selected specialized areas. Clients can take advantage of the working relationships among SENES and its affiliated companies to access the outstanding technical and scientific capabilities offered by each company.

SENES provides environmental services across a wide range of sectors, and specializes in work related to radioactivity. Since the firms inception, SENES has carried out more than 1500 radiation related projects, ranging from personal service efforts including the provision of individual expert support and advice or peer review, through to full scale multi-discipline development and cleanup projects. In the course of these projects our clients have included uranium mining companies, uranium refineries, fuel fabrication facilities, nuclear power plants laboratories, numerous industrial clients, industry associations and federal and international agencies and regulators. To these clients, SENES provides expertise in:

- health physics;
- environmental assessment;
- air and water quality assessment and modelling;
- environmental audits and liability assessments;
- radioactive and hazardous waste management;
- development of remedial action plans;
- decommissioning and closure; and
- human health and ecological risk assessment and management.

The focus of this selective summary is to provide a cross section of typical projects illustrating our experience on issues related to radioactivity.

- Ecological Risk Assessment
- Risk Assessment
- Closeout, Decommissioning and Reclamation
- Environmental Assessment
- NORM
- Radiological Surveys

We would be pleased to answer any enquiries and can be contacted at the address below. Additional information is available through visiting our web site at **http://www.senes.on.ca**

SENES CONSULTANTS LIMITED
121 Granton Drive, Unit 12
Richmond Hill, ON
L4B 3N4
Phone (905) 764 9380 Fax: (905)764-9386 Email: dchambers@senes.on.ca

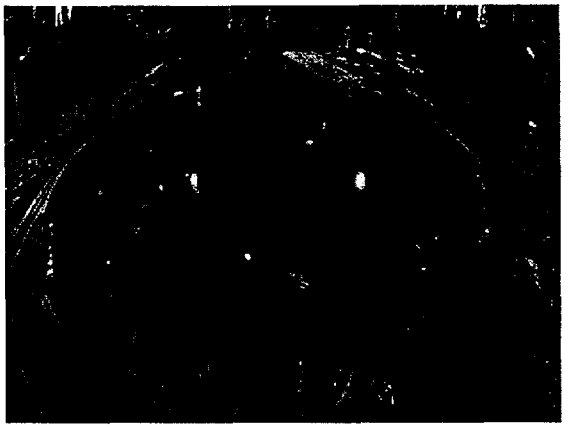
ECOLOGICAL RISK ASSESSMENT

PICKERING NUCLEAR GENERATING STATION ECOLOGICAL RISK ASSESSMENT

Building on a previous "Environmental Review" of the Pickering Nuclear Generating Station (PNGS) conducted by SENES, a Tier I Ecological Risk Assessment was undertaken. Relevant information was extracted from the Environmental Review report and the various findings were integrated using ERA methodology to identify key effects and potential risks of PNGS operations on ecosystem components of concern at the PN site. The study, which focused on the ecological effects of both radioactive and chemical contaminants, considered the diverse urban, industrial and natural environment of the PNGS site. Following from the Tier I assessment, SENES marshalled an international, multi-disciplinary team for the PNGS Tier II. Study components identified during Tier I as requiring additional examination were examined including: obtaining additional data; modelling groundwater and surface water interaction; studying contaminant levels in indicator organisms; and refining the environmental compartment modelling.
(Ontario Power Generation)

BLIND RIVER AND PORT HOPE ECOLOGICAL RISK ASSESSMENT

A multi-tiered assessment was completed as part of an environmental effects monitoring study at the Cameco Port Hope and Blind River facilities. Environmental media considered included: air, surface water, sediment, groundwater and soil. Air modeling of current emissions was used to estimate air concentrations at locations of maximum exposure and to study the long-term impacts of deposition from air on soil concentrations. Pathways analysis, exposure assessment (including food chain effects) and risk analysis were completed. Aquatic and terrestrial non-human biota were assessed. *(Cameco Corporation)*



BRUCE NUCLEAR GENERATING STATION ECOLOGICAL RISK ASSESSMENT

An ecological risk assessment was carried out in support of an environmental assessment of the proposed expansion of the Radioactive Waste Operations Site 2 (RWOS2) at the Bruce Nuclear Power Development. Ecological receptors included fish, amphibians, benthic invertebrates, aquatic plants, terrestrial plants, terrestrial invertebrates, birds and mammals. The assessment considered only radiation dose from anthropogenic radiation sources. The Tier 1 assessment indicated that some receptors had screening indices greater than 1 and therefore a Tier 2 analysis was carried out. The Tier 2 analysis found that the doses to all receptors were acceptable. *(Ontario Power Generation)*

PORT RADIUM MINE– SITE, HUMAN HEALTH & ECOLOGICAL RISK ASSESSMENT, DECOMMISSIONING PLANNING

SENES carried out a series of initiatives over several years in association with the assessment of potential environmental and human health concerns surrounding the Port Radium mine, located on the north-eastern shore of Great Bear Lake approximately 4 degrees south of the Arctic

Circle. Activities included participation in an Experts Workshop with the community of Déline to establish a framework for collaborative efforts between the Government of Canada and the Dene Nation, and conducting several site assessments carried out for the Department of Indian Affairs and Northern Development (DIAND) and the Canadian Déline Uranium Table (CDUT) to identify the environmental status and conditions at the site.

The preliminary site efforts included compilation and review of existing data, interviews with former operators and related parties, and design and implementation of a winter field program to gather site-specific information. The winter program, carried out in association with the community of Déline collected water, waste rock, and tailings samples, set radiation monitors, and gathered site wide gamma radiation measurements. Results of the program were combined in a report that identified site conditions, provided a discussion of potential hazards and risks, summarized existing information and data gaps, commented on potential decommissioning requirements, and presented action recommendations to support the development of future full-scale site assessment of potential human health or ecological risks.

Subsequently, as a first part of a Three Year Action Plan developed by the CDUT, SENES was retained to carry out a more detailed site assessment program to further refine the assessment of potential human health and environmental issues. The project included additional characterization and delineation of contaminant sources, further definition of site conditions and pathways through a field program that included water sampling, tailings and waste rock sampling, geophysical (ground penetrating radar) measurements, air sampling, radiation measurements and monitoring, local biota sampling, and surveying of site topographic features for future mapping. A site-specific risk assessment framework was used to guide the development of a quantitative screening level human health and ecological risk assessment for the site and decommissioning options and alternatives were identified and assessed for future consideration. As with the first program, the project was carried out in association with the community of Déline. Based on the findings of these programs SENES developed a quantitative human health and ecological risk assessment for the site and several decommissioning options for consideration by DIAND and the CDUT.

Ecological Risk Assessment of Uranium Mining in Northern Saskatchewan

In the first phase of this two phase study, a screening level ecological risk analysis was performed to examine the potential risks posed by uranium mining in the McArthur River region in northern Saskatchewan. The probable responses of populations of eight aquatic and seven terrestrial "valued ecosystem components" (VECs) were evaluated in relation to expected exposures to twenty-three potential contaminants (including radionuclides, metals and other physical and chemical parameters). The results of the screening level assessment were used to: (1) identify the contaminants that appear to pose no direct threat to the VECs of interest; and (2) point out the combinations of populations and contaminants that should possibly by examined in greater detail because of the potential for ecological impact. In the second phase of this study, a more detailed assessment was performed for caribou and wolf exposure to seven potential contaminants (including radionuclides and metals). A detailed computer simulation employing environmental transfer and uptake models and quantitative uncertainty analysis was performed. *(Cameco Corporation)*

HUMAN HEALTH AND ECOLOGICAL RISK ANALYSIS FOR THE CLINCH RIVER ENVIRONMENTAL RESTORATION PROGRAM

In the Remedial Investigation/Feasibility Study for the Clinch River/Poplar Creek Operable Unit, SENES participated in the human health risk assessment for this major Superfund site. The studies involved risk assessments and remedial investigations of the off-site release of contaminants from the Oak Ridge Facilities, including the Oak Ridge National Laboratory, the former Gaseous Diffusion Plant (K-25), and the Weapons Production Plant (Y-12). *SENES* was responsible for reviewing the entire report and providing advice for the conduct of the human health risk assessment. In addition, SENES conducted the uncertainty analysis for the human health risk assessment and was responsible for the radiological dose calculations for the terrestrial and aquatic biota and for predicting the ecological effects from the calculated doses. Human health and ecological risk assessments were conducted for the contaminants of concern, including both organic compounds and heavy metals. This project involved QA/QC for the collection and analysis of data. (*Lockheed Martin Energy Systems*)

CONCEPTUAL RISK ASSESSMENT FOR RHONE RIVER, FRANCE

As part of a public review process, expert reviews of a series of detailed radioecological monitoring reports were undertaken for a French government nuclear agency and a local commission of the "département du Gard". The rigour of conclusions and supporting arguments provided in the reports, as well as the adequacy of the sampling program undertaken and the methodology taken were reviewed and evaluated.

The reports consist of results and interpretations of radioecological monitoring programs on the levels of various artificial radionuclides encountered in aquatic and terrestrial compartments released from a large nuclear complex located in the southern part of France. This nuclear complex includes: a fuel reprocessing facility, a fast-breeder reactor (phénix), military related reactors, as well as other nuclear supporting facilities. The reports include various measurements of fission products (e.g., ^{137}Cs, ^{134}Cs, $^{106}Rh+Ru$), activation products (e.g., ^{60}Co, ^{58}Co, ^{54}Mn), transuranics (e.g. ^{241}Am, $^{239/240}Pu$, ^{238}Pu), and tritium in aquatic indicators (surface and underground water, aquatic vegetation, fish species and sediments) and terrestrial indicators (soil and terrestrial vegetation), but also in some food chain products (milk, wine, grapes and fish). One of these reports specifically addressed levels of tritium in leaves resulting from atmospheric emissions of tritium.

ECOLOGICAL RISK ASSESSMENT OF HIGH LEVEL NUCLEAR WASTES

A review of Canada's nuclear waste disposal concept, as developed by Atomic Energy of Canada Limited (AECL), was conducted on behalf of Environment Canada on aspects related to the natural environment. Independent ecological risk assessment calculations were performed for both the pre-closure and the post-closure phases of the disposal concept. Scoping calculations were carried out to evaluate the impacts of habitat loss and radiation dose rates within a synthetic reference environment representing a hypothetical location in the Canadian Shield. Population level endpoints were considered for both moose and brook trout. The results indicated that radiation effects associated with normal facility operation would not be measurable at the population level. *(Environment Canada)*

HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT FOR DECOMMISSIONING A URANIUM MINE

This study involved predicting the release of radionuclides from the flooded tailings using the Uranium Tailings Assessment Program (UTAP.3w). The UTAP model, developed by SENES, contains a comprehensive source term that models the long term geochemical reactions within a sulphidic uranium mill tailings environment. The detailed probabilistic modelling

of radionuclides and metals through the environment and the potential uptake by humans and aquatic and terrestrial receptors was evaluated using the INTAKE model. INTAKE an in-house model also developed by SENES, for simulating environmental transfer and risk. Ecological receptors were selected from each trophic level for the assessment. Potential exposures were then compared to the applicable toxicity data and the possible combinations of receptors and contaminants of concern were identified. *(Rio Algom Ltd.)*

RISK ASSESSMENT

AGRICULTURAL AND ROAD CONSTRUCTION USES OF PHOSPHOGYPSUM CONTAINING RA-226

SENES prepared a dose and risk assessment of potential impacts on workers and members of the public from agricultural and road construction uses of phosphogypsum (a by-product of phosphate production for fertilizer) in Florida. Phosphogypsum from central Florida contains an average of 26 pCi/g Ra-226 and some of its uses are prohibited by the United States Environmental Protection Agency. Screening calculations of several exposure pathways (external gamma radiation, radon progeny, inhalation of dust, and ingestion of dust, garden produce and animal products) were made to identify those pathways which resulted in the highest risk and required detailed assessment. Probabilistic methods were used to more accurately estimate the distributions of potential dose and lifetime risk from exposures to external gamma radiation and radon progeny and to compare them to regulatory criteria. (*Florida Institute of Phosphate Research*)

NATIONAL URANIUM TAILINGS PROGRAM (NUTP)

In the 1980s, SENES undertook the study for the NUTP to assess the role of bacteria in the oxidation of pyritic uranium tailings. The study included a critical evaluation of the literature to identify deficiencies and to make recommendations for additional work. Factors which affect the rate of bacteria-assisted oxidation of pyritic material include: the geochemistry and reactivity of the pyritic material; the amount of pyrite present in the waste material and the exposed surface area of the pyritic component; the availability of oxygen which is the principal electron acceptor; the availability of carbon dioxide which is the sole source of carbon for the strictly chemolithotrophic bacteria of interest; the pH of the leach solution (e.g. tailings porewater); the temperature of the leach solution (e.g. tailings porewater); and presence (or absence) of organic inhibitors. Of the above factors, oxygen has been frequently identified as the rate limiting reactant in tailings. The implications of close-out concepts to limit oxygen accessibility to the tailings were also evaluated. *(Energy Mines and Resources Canada; now Natural Resources Canada)*

HUMAN HEALTH RISK ASSESSMENTS FOR URANIUM MINING

Human health risk assessments were performed to examine the potential exposures of nearby residents to radionuclides due to uranium mining in northern Saskatchewan and northern Ontario and to background sources of radiation. Environmental pathways analysis were performed to assess radionuclide movement through the environment to humans. The INTAKE model used for this assessment, developed through and applied to numerous previous projects and applications

spanning more than a decade, traditionally evaluates incremental doses. The model was adapted to allow for the evaluation of background exposures and total doses (i.e. including background levels of radiation). The INTAKE model is set up within a probabilistic framework incorporating uncertainty and natural variability of model parameters into the calculations. *(Amok/Cluff Mining, Cameco Corporation, Denison Mines Limited, Minatco Limited, Midwest Joint Venture, Rio Algom Limited)*

ACLs for Uranium Tailings Pile

Homestake Mining Company of California was decommissioning its uranium tailings pile at Grants, New Mexico. After corrective actions have been terminated, uranium, selenium and molybdenum concentrations in groundwater were expected to exceed drinking water criteria. Therefore, Homestake applied for alternate concentration limits (ACLs) for these three metals in groundwater to the Nuclear Regulatory Commission. In support of the application, Homestake prepared a risk assessment that described the expected movement of the metals from the tailings pile into the surrounding groundwater, the potential exposures to nearby residents from ingestion of drinking water and from irrigation of foodstuffs and the potential toxic impact. The assessment also addressed alternate corrective actions, corresponding alternate concentration limits and demonstrated that the recommended limits were as low as reasonable achievable considering other social and economic factors. SENES played a key role in organizing the structure of the assessment and in developing details of the pathways, exposure and toxicity analyses. *(Homestake Mining Company of California)*

Evaluation of UF_6 Releases

SENES evaluated the usefulness and effectiveness of currently existing models for analyzing accidental releases of uranium hexafluoride (UF_6) from fuel cycle facilities. The NRC requires licensees to conduct an Integrated Safety Analysis (ISA), to develop an Emergency Response Plan (ERP) and, in the event of an accidental release of UF_6, to conduct a Post-Accident Analysis (PAA) to evaluate both the severity of the accidental release and potential health impacts on the local population. Models specifically developed for UF_6 and those developed for the treatment of dense gases that are potentially applicable to UF_6 release, reaction and dispersion were examined. Both screening-level and detailed public-domain models were evaluated. Evaluation involved assessment of model components; applicability to ISA, ERP, and PAA; and user interface and QAQC. Within the component evaluation process, a models treatment of source term, thermodynamics, and atmospheric dispersion were evaluated and comparisons among model predictions and with actual observations were conducted. (U.S. *Nuclear Regulatory Commission*)

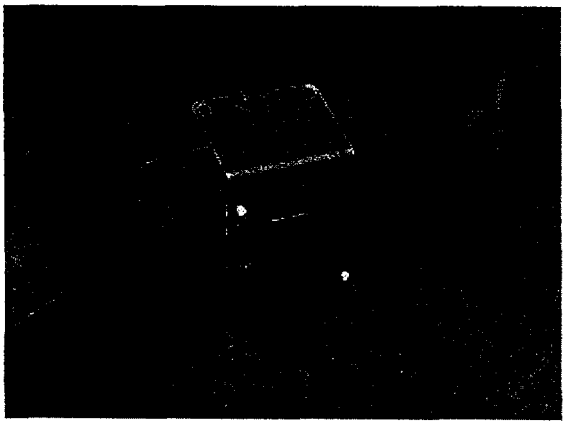
Radon Decay Product Exposures to Underground Workers at the Eldorado Beaverlodge Uranium Mine

As part of a three-phase project, SENES re-evaluated the exposures to radon decay products of uranium miners at the Beaverlodge mine in northern Saskatchewan. The first phase of the study examined the available data and assessed the reliability of previous estimates of both radon decay product levels (WL) in the mine and the radon decay product exposures (WLM) of the men who worked in the mine. The re-evaluated exposure were, on average, lower than the exposure estimates previously used in epidemiological analyses; however, a large amount of uncertainty in individual employee exposures was evident based on a high spatial variability in radon decay product levels throughout

the mine. The second phase involved a detailed investigation of the Beaverlodge records to further improve the estimates of the exposures of a case control group. Exposure rates specific to the area and the time when the individuals worked, rather than mine-wide estimates, were assigned to individuals. In the third phase, an algorithm was developed to estimate exposures of the entire cohort to radon decay products based on occupation and employment duration information previously compiled by the original investigators. The uncertainties in exposures using the cohort algorithm were estimated. *(Atomic Energy Control Board of Canada)*

RE-EVALUATION OF RADON DECAY PRODUCT EXPOSURES TO UNDERGROUND WORKERS AT THE PORT RADIUM MINE

Radon decay product (RDP) concentrations and exposures (WLM) to underground employees in a case-control group from the Port Radium uranium mine were re-evaluated. The re-evaluation was based on a detailed review of mine data for the period 1942-1960, a review of published literature and interviews with selected number of former Port Radium employees familiar with mine operations, ventilation and radiation protection at Port Radium. *(Atomic Energy Control Board of Canada)*



FEASIBILITY STUDY INTO THE RE-EVALUATION OF EXPOSURE DATA FOR THE COLORADO PLATEAU URANIUM MINER COHORT STUDY

The Colorado Plateau cohort of uranium miners is an extremely valuable resource in that it currently provides one of the strongest bases for risk estimation for groups exposed to radon daughters. Although there is no known systematic bias with regard to the magnitude of the exposures estimated with this cohort, the uncertainties in exposures are very large, particularly those exposures associated with the early years of uranium mining. These large uncertainties could affect the epidemiological analyses of this cohort.

In 1995, SENES conducted a preliminary feasibility study into the re-evaluation of exposure data for the Colorado Plateau cohort. Data on mine workplace conditions was examined with respect to variability within mines, among mines, by mining district and by state. A small test cohort of miners was selected from the larger cohort to determine the potential for reconstruction of exposures, and to determine any possible bias introduced in the earlier exposure estimates. All other available information was also reviewed to determine any possible bias in earlier estimates. *(National Mining Association, Washington DC)*

UNCERTAINTY ANALYSIS FOR DOSE RECONSTRUCTION MODELS

The goal of this study was to provide Center for Disease Control in Atlanta (CDC) with an objective evaluation of a variety of quantitative and qualitative methods for uncertainty analysis, with special consideration for the application of these methods to dose reconstruction models. Specific efforts will focus on the definition of those situations that require quantitative uncertainty analysis and the evaluation of different approaches for these analyses. Methods for uncertainty analysis will be evaluated for their applicability to different types and sizes of models. Ease and cost effectiveness of use, clarity of interpretation, and defensibility of the final result will also be considered. The ultimate goal of the project is the application of quantitative uncertainty analysis to specific case studies of interest to CDC. In this project, formal working relations have been established with other scientists who are internationally renowned for their pioneering work in the use of quantitative uncertainty analysis in radiological and chemical risk assessment. SENES (Toronto) developed methods for screening epidemiological feasibility and dose-response analysis taking uncertainty in dose into account. (*Centers for Disease Control, Atlanta*)

SENES has performed hundreds of risk assessments which examine the potential risks to people and the environment for both radioactive and non-radioactive hazards. Examples include the evaluation of risks from drinking water (chemical and pathogens) and the development of a risk based decision model for selecting the preferred water management alternative, risk assessment and risk management for industrial contaminated sites, risks from LNG storage facilities and risks from accidental releases of UF_6, anhydrous HF, anhydrous ammonia and other agents. Consideration of the sources and effects of uncertainty are important considerations.

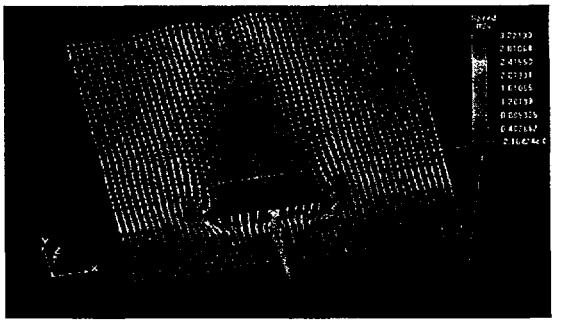
WEST CHICAGO LITIGATION SUPPORT

In 1931, the Lindsay Light and Chemical Company established a thorium extraction facility in West Chicago, Illinois. Later operations included the recovery of rare-earth elements also present in the ores. Solid wastes containing uranium and thorium series radioactivity were stored on-site. In 1967, ownership of the ore processing site passed to Kerr-McGee Chemical Corporation. Seven years later in 1974, Kerr-McGee terminated operations and planned: the decommissioning of the site; the termination of the licence from the Illinois Department of Nuclear Safety (IDNS); and the return of the site to unrestricted use. Subsequently, throughout Kerr-McGee's decommissioning activities, various lawsuits have been initiated alleging that radiation and radioactivity associated with the West Chicago site has had a deleterious effect on people living in the proximate area.

On behalf of Kerr-McGee counsel, SENES undertook detailed analysis of possible radiation doses to plaintiffs in various lawsuits. The SENES dose reconstructions played a key role in resolving the lawsuits. *(Covington and Burling)*

ACCIDENTAL RELEASES OF UF6 – SEQUOYAH FUELS CORPORATION

On 4 January 1986, there was an accident at the Sequoyah Fuels Corporation facility at Gore Oklahoma that led to the rupture of a 14 ton cylinder of uranium hexafluoride (UF6), SENES used available data to carry out a post accident analysis of chemical concentrations of UF6, UO2F2 and HF. The starting point for the analysis was the development of a time dependent, thermodynamic based model for the release of UF6. Since UF6 is reactive with water, the analysis also developed thermodynamic models for converting UF6 release into UO2F2 and HF. The air dispersion analysis took account of building configurations and local weather. Measured concentrations in soil and vegetation were used to calibrate the model, which predicted time dependent concentrations of UF6, UO2F2 and HF in the air at various downwind locations. All of the models were embedded in a Monte Carlo framework. The predicted concentrations compare dwell to available data. *(Kerr-McGee)*



CLOSEOUT, DECOMMISSIONING AND RECLAMATION

SOIL RELOCATION PROJECT

A detailed environmental screening assessment was carried out for the proposed relocation of approximately 200,000 tonnes of contaminated soils and sediment from several major areas within the Town of Port Hope, Ontario (e.g. three ravines, the municipal garbage dump, a small dam, the harbour, and four open areas). The actual removal operation was postponed pending the establishment of a permanent disposal site. *(Low-Level Radioactive Waste Management Office)*

STANLEIGH URANIUM MINE

SENES also prepared a Comprehensive Study Report under the Canadian Environmental Assessment Act for the decommissioning of the Stanleigh mine, mill and waste management area. The report includes project alternatives, the decommissioning plan, an assessment of all decommissioning activities, the predicted environmental effects of these activities, mitigative measures, follow-up (monitoring) program, and the public consultation activities. SENES was also responsible for the development of the public consultation program and assisted the client in implementing the program. *(Rio Algom Limited)*

AGNEW LAKE URANIUM MINE

Assistance was provided to Agnew Lake Mines in the acquisition of approval from the Atomic Energy Control Board to allow its decommissioning license to lapse. SENES completed a pathways analysis for the site and co-ordinated and submitted the final monitoring summary report for the five-year transition monitoring phase. SENES also provided testimony before a hearing in support of Agnew Lake's application which was approved. Ownership of the property now resides with the Province of Ontario. *(Kerr Addison Mines Limited)*

ATLAS TAILINGS PILE RECLAMATION

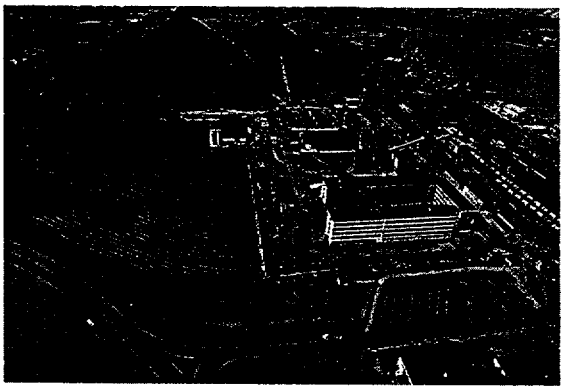
SENES undertook a comparative screening level risk assessment of the proposed on-site reclamation plan and an alternative off-site reclamation option for this 10.5 million ton uranium tailings pile situated near Moab, Utah. The project included review of planned activities and assessments of associated radiological and non-radiological risks to the environment, public, and reclamation workers along with a comparison to the "no action" base case. In its EIS assessment, U.S. NRC staff concurred with the results of the SENES risk analysis.

SENES also reviewed the U.S. NRC regulatory and decision making framework, a review of Title I and Title II reclamation precedents and costs, carried out probabilistic cost estimate sensitivity analyses, and assisted Atlas and national counsel in development and presentation of public information and in producing comprehensive responses to U.S. NRC's DEIS. *(Atlas Corporation)*

BEAVERLODGE URANIUM MINE

An engineering feasibility study was undertaken by SENES to assess the engineering requirements and the environmental and cost implications of several potential reclamation concepts for the ultimate close-out of the Beaverlodge uranium mine/mill facility in northern Saskatchewan. Reclamation concepts were developed for each component of the mine/mill facility including the tailings areas, tailings spills, waste rock piles, mine water sludges, mines, mill and ancillary facilities. Detailed pathways analyses were subsequently undertaken for selected reclamation options. Site-specific radiation measures, an evaluation of eating habits specific to the area, and a literature search of critical pathways parameters (e.g. water to fish transfer factors) were used to estimate the potential radiation exposures resulting from several reclamation options. A water quality model was developed mainly to simulate uranium and radium-226 levels over an extended timeframe for input to the pathways analysis. The mine was successfully decommissioned and reclaimed. The Province of Saskatchewan and Eldorado Resources (now Cameco) have jointly participated in monitoring the transition years. The facility has performed as expected and negotiations are ongoing for transfer of the property back to the Crown. *(Eldorado Resources Limited)*

GERMANY URANIUM MINES



SENES headed a team of Canadian consultants retained to advise the German Environment Ministry (BMU) on the decommissioning of Wismut's uranium mining facilities in Saxony and Thüringea. The Wismut sites are only part of a larger problem that includes 2,000 nearby historic and abandoned waste sites. SENES, in addition to co-ordinating project activities, has direct responsibility for environmental issues including, but not limited to, evaluation of decommissioning criteria and the assessment of decommissioning plans proposed by Wismut. Acid mine drainage, the release of toxic metals and radionuclides to the environment, ecological and human health risks are among the areas of concern. *(German Environment Ministry)*

RABBIT LAKE URANIUM MINE

To assess the impact of a waste rock pile and open pit, laboratory scale leaching studies were designed and evaluated to determine the acid generation potential and the leachability of metals and radionuclides from the mine wastes. The project involved the development of a water quality model to assess reclamation strategies for the B Zone open pit and waste rock pile developed adjacent to Collins Bay on Wollaston Lake. The model simulated metal and radionuclide leaching from waste rock, mineralized waste and exposed ore and evaluated the potential benefits of reclamation alternatives. Pathways analyses to estimate the radiation exposure of local residents in the Wollaston Lake area of northern Saskatchewan were also prepared. *(Cameco Corporation)*

SITING TASK FORCE

The Siting Task Force (STF) on Low-Level radioactive Waste Management was established by the federal government in 1989 to implement a Co-operative Siting Process to site a facility for the long-term management of the Port Hope Areas wastes. SENES was retained by the Siting Task Force Secretariat to provide consultative services on various aspects of the project including: characterization of the Port Hope Area hazardous wastes (both low-level radioactive and chemical contaminants); assistance in the development of cleanup criteria applicable to the various waste sites; design and implementation of a field sampling program to upgrade existing waste characterization data and better delineate waste occurrences at the Port Granby and Welcome Waste Management Facilities (WMFs); input to the design of remedial action plans for the major waste occurrences; assessment of potential transportation of options for the transport of approximately 1 million cubic metres of wastes to

the candidate disposal sites at Deep River and Port Hope, Ontario; and co-ordination of project issues to ensure compliance with federal environmental assessment requirements. (*Siting Task Force on Low-Level Radioactive Waste Management Phase 4*)

CLEAN-UP OF LOW-LEVEL RADIOACTIVE WASTE

Pre-development radiation surveys conducted by SENES on vacant land in the Malvern area of Metropolitan Toronto identified four piles of soil containing low-level radioactive material. The source of the radioactivity was found to be radium contained in small pieces of plastic tubing. A remedial program was designed and implemented to separate the pieces of tubing from the bulk soil, and to concentrate the major portion of the radioactive inventory. Computer-assisted radiation detectors were used to test the soil and identify the presence of tubing pieces. Approximately 2,500 cubic metres of soil were processed and close to 20,000 pieces of tubing were recovered and shipped off-site to a licensed waste management facility. SENES personnel were involved in all aspects of the project including pre-development radiation surveys, identification of contamination, design of the soil processing operation, preparation of an environmental review of the proposed clean-up operation following the Federal Environmental Assessment Review Office (FEARO) protocol, operation of a public information office, operation of the soil processing system, and participation in the Malvern Remedial Action Committee established by the Federal and Provincial governments to develop appropriate management plans for the waste. *(Low-Level Radioactive Waste Management Office)*

WEST CHICAGO THORIUM PLANT (KRESS CREEK)

Over the years, some of the wastes containing radioactive contamination were transported, presumably through a storm sewer, from the thorium extraction facility in West Chicago to Kress Creek, a tributary of the West Branch of the Dupage River, and caused thorium contamination along the banks of the Creek and the River. SENES analysed the available radiological data and prepared an assessment of the existing radiological conditions along Kress Creek. Representative dose calculations from radon and thoron progeny and from ingestion of vegetables grown in contaminated soil were made. The report focussed on responses to questions from the Nuclear Regulatory Commission. *(Kerr-McGee)*

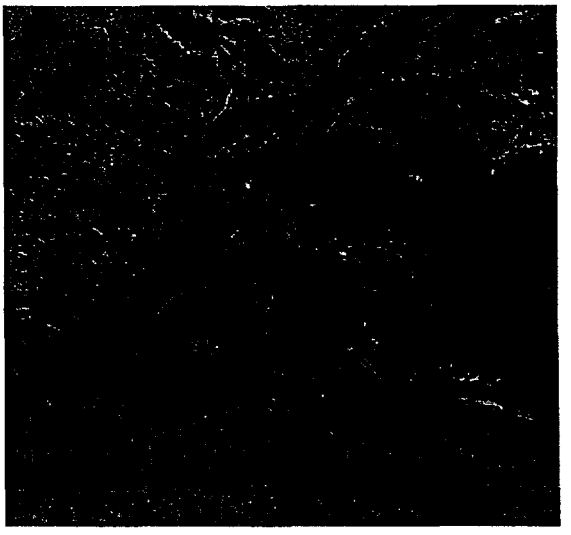
RADIOLOGICAL ASSESSMENT AND DECOMMISSIONING

In preparation for decommissioning the West Chicago site, Kerr-McGee constructed facilities to provide for control of emissions to the environment and to facilitate retrieval, processing and loading for transport of the contaminated materials. SENES prepared a screening level impact assessment of the potential radiological impacts from contaminated dust, and radon and thoron progeny to on-site workers and the members of the public potentially exposed during preparatory work. The resuspension of contaminated dust by the wind and by earth-moving equipment was estimated using EPA models that incorporated site-specific parameters such as wind-speed, moisture content and exposed area. The exhalation of radon and thoron from exposed waste and their release from pore spaces during waste removal were calculated using factors recommended by EPA and NRC. The atmospheric dispersion of radon, thoron, their progeny and particulate radioactivity were estimated at nearby residences by modelling atmospheric dispersion using local weather data and the ISCLT model recognized by the United States Environmental Protection Agency. Similarly, after the construction of support facilities and removal of contaminated tailings to disposal (Phase I) SENES prepared a screening level impact assessment of the potential radiological impacts associated with the work. *(Kerr-McGee)*

MOAB RECLAMATION TRUST

As part of the bankruptcy agreement, the Moab Reclamation Trust (Atlas, NRC and the State of Utah) administered by PricewaterhouseCoopers LLB, was established to provide interim administration of the NRC Source Material License for the Atlas Mill and tailings site located on the Colorado River, near Moab, Utah. In carrying out its License requirements the Trust initiated several studies and actions in support of the approved decommissioning plan for the site SENES was

retained by the Trust to provide strategic and long-term environmental planning advice on proposed environmental programs for the site including water quality assessments, engineering plans for dewatering and earthworks, and proposed radiation monitoring programs. SENES also carried out a comprehensive independent review and assessment of ALARA reports to NRC for the period from 1995 to 2000, and developed an application for exemption from the 100mrem/yr limit pursuant to 10 CFR Part 20 - 1301(c) from NRC in support of the proposed decommissioning works. The application included complete technical analysis of radioactivity issues associated with proposed decommissioning works and the potential effects on the nearest resident. The NRC approval of the application was the first such approval provided by NRC and is a precedent for the industry.



ENVIRONMENTAL ASSESSMENT

SENES has performed numerous environmental impact assessments for mining, industrial and governmental clients. SENES personnel prepared the first EIS under the Federal Environmental Assessment Review Process (for the Point Lepreau NGS) and have been active in the Federal process since then. SENES have also performed or participated in numerous EIS in Saskatchewan and Ontario and in essentially all of the environmental assessments performed for uranium mining and processing in Canada. A few examples are given below.

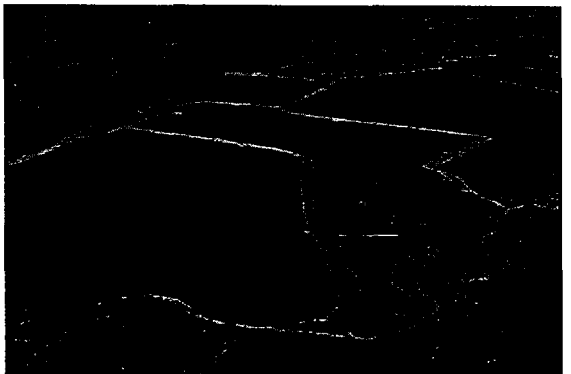
DECOMMISSIONING OF URANIUM MINES - ELLIOT LAKE AREA, ONTARIO

SENES has participated in many investigations over a period of 20 years aimed at the development of decommissioning plans for several uranium mines, mills, and associated waste management areas located in the Elliot Lake region of northern Ontario. This work has progressed through reviews of options, preparation of environmental and radiological pathways analyses, presentation of the decommissioning proposals to the Atomic Energy Control Board (AECB) and preparation of environmental screening reports for submission to the AECB in accordance with the former federal EARP process. All decommissioning activities and their attendant environmental impacts were identified; specific ameliorative and mitigative actions were recommended as required. Two comprehensive Environmental Impact Statements (EIS) of the waste management areas were prepared to comply with panel guidelines; assistance was provided to Rio Algom Limited and Denison Mines Limited in preparation for hearings under EARP. The EIS's were approved by the environmental assessment panel. Most recently, SENES prepared a Comprehensive Study Report under the Canadian Environmental Assessment Act for the decommissioning of another mine, mill and waste management area, and was also responsible for the development of the public

consultation program. The report was approved and licences to decommission have been issued. *(Rio Algom Limited/Denison Mines Limited)*

McARTHUR RIVER

In Phase 1 of this two phase study, an exposure assessment was performed to examine the potential exposures to radionuclides due to uranium mining in the McArthur River region of northern Saskatchewan and to background sources of radiation. An environmental pathways analysis was performed to assess radionuclide movement through the environment to humans. The INTAKE model used for this assessment, developed through and applied to numerous previous projects and applications spanning more than a decade, traditionally evaluates incremental doses. The model was adapted to allow for the evaluation of background exposures and total doses (i.e. including background levels of radiation). The SENES INTAKE model is set up within a probabilistic framework incorporating uncertainty and natural variability of model parameters into the calculations. In the second phase, human health risks due to radiation doses and exposures to heavy metals via airborne and



aqueous emissions were estimated. In Phase II, detailed human health risk assessments and ecological risk assessments were performed. (*Cameco Corporation*)

HIGH-GRADE URANIUM DEPOSIT TEST MINE, SASKATCHEWAN

An environmental impact assessment was prepared for a proposed underground, high-grade uranium mine. A test mine was to be used to evaluate sub-surface conditions and the mining technologies to be used. The assessment included a review of the environmental data for the mine site and vicinity, identification of possible impacts and mitigative measures, and development of a monitoring program to be followed during mine operation. From inception to licence approval, the project was completed within a year. *(Midwest Joint Venture)*

URANIUM MINING

In addition to such EIS studies, SENES has performed numerous studies in support of mining high grade uranium properties in northern Saskatchewan. Many of these have a radiological focus, including:

- Assessment of worker exposures at the Cluff Lake uranium mine relative to new AECB regulations;
- Development of the radiation protection section of COGEMA's application for the JEB mill;
- Review of the radiation protection aspects of the basic design for the proposed JEB mill expansion (based on the proposed Cigar Lake mill design) and development of the radiation protection design manual for the JEB mill expansion;
- Participation in a feasibility study on workplace radiation protection for the McArthur River project;
- Completion of a detailed gamma survey at the Key Lake mill and a related assessment of worker exposures and shielding requirements for two milling scenarios (i.e. increase of the mill ore grade from about 2 $\%U_3O_8$ to 4 to 20 $\%U_3O_8$) in support of the feasibility study just mentioned above;
- Participation in development of alternatives for test mining at Cigar Lake and associated radiological evaluation (with Pierre Zettwoog);
- Participation in a feasibility study for mining of Eagle Point deposit and associated radiological evaluation;
- Analysis of implications of proposed new AECB regulations on mining in Ontario and Saskatchewan. *(Rio Algom and Uranium Saskatchewan)*

These studies required: the evaluation of various mine/mill environments, shielding alternatives, mining/milling and ore handling methods, upset scenarios and related contingency measures; the characterization of various radioactive source terms; and the optimization (ALARA) of proposed and existing mining/milling installations and activities at the feasibility, conceptual and detailed engineering levels.

CUMULATIVE EFFECTS ASSESSMENT FOR THE BRUCE NUCLEAR GENERATING STATION, ONTARIO

SENES and Gartner Lee Limited prepared a cumulative effects assessment as part of Ontario Hydro's Comprehensive Study Report for a Used Fuel Dry Storage Facility (UFDSF) at the Bruce site in accordance with the requirements of the Canadian Environmental Assessment Act and the draft Cumulative Effects Guide (1997) prepared by the Canadian Environmental Assessment Agency. The intent of the cumulative effects assessment was to assess environmental effects of the project over a large regional area as well as the longer time period into the past and the future. The cumulative effects of the UFDSF on key environmental factors and Valued Ecosystem Components were evaluated, giving consideration to: existing operations (Bruce B, RWOS 1 and 2, Douglas Point); ancillary facilities (the steam plant and central maintenance facilities); and, proposed projects (RWOS 2 upgrade, including incineration, additional inground container storage facilities, waste removal from RWOS 1, heavy water plant decommissioning and steam plant replacement). Assessment also considered the cumulative effects resulting from the restart of Bruce A, and the eventual plant shut down and safe storage of Bruce A and B. *(Ontario Hydro)*

ENVIRONMENTAL REVIEW OF PICKERING NUCLEAR GENERATING STATION, ONTARIO

SENES and Gartner Lee Limited conducted a comprehensive review of the effects of the Pickering Nuclear Generating Station (PNGS) on the biophysical environment surrounding the station. This review was required by the Atomic Energy Control Board as a condition for renewing Ontario Hydro's licence to operate the Pickering Nuclear Station. The review dealt with the biophysical effects of PNGS and the preparation of an environmental action plan. Of particular interest was the analysis of the effects of radioactive and non-radioactive emissions on Valued Ecosystem Components (VECs) such as groundwater, Lake Ontario surface and drinking water, air, inshore and lake-wide fish populations and adjacent marshes and bays. The review involved setting up, meeting with, and having material reviewed by a Community Working Group (CWG). Screening studies were prepared to determine possible effects and a priority system for a ten-point program to address the issues.
Elements of that program included, among others, actions to improve data gathering and monitoring, specific actions to address VECs, recommendations for the introduction of Statistical Process Control and Facility Risk Management techniques and the development of five-year environmental actions plans. *(Ontario Hydro)*

DARLINGTON USED FUEL DRY STORAGE ENVIRONMENTAL ASSESSMENT (DUFDS)

Power Generation Inc. (OPG) is proposing to develop the a Used Fuel Dry Storage facility at the Darlington Nuclear Generating Station property to store fuel, that has been previously cooled at least ten years under water, in dry storage containers. SENES was part of a multi-disciplinary team of environmental consulting firms to carry out the environmental assessment for the twenty-two month project that includes the preparation of an EA study report and all necessary supporting materials meeting the requirements of CEAA, for submission to the Canadian Nuclear Safety Commission. SENES involvement in the environmental assessment includes review of

atmospheric and noise environments, socio-economics, radiation and radioactivity, risk and hazard assessment, and cumulative effects assessments. *(Ontario Power Generation Nuclear)*

LEPREAU NUCLEAR GENERATING STATION, NEW BRUNSWICK

Scientific and project management services were provided during the preparation of the site selection study for the first nuclear generating station in the Atlantic provinces. Subsequently, the EIA for the selected site at Point Lepreau, New Brunswick was prepared. Field monitoring programs were designed and implemented and major contributions made on various aspects of atmospheric dispersion, radioactivity, and cooling water discharge. Expert testimony was provided at federal and provincial hearings. Similar contributions were provided for the environmental assessment of a second reactor proposed for Lepreau. *(New Brunswick Electric Power Commission)*

PICKERING WASTE MANAGEMENT FACILITY PHASE II ENVIRONMENTAL ASSESSMENT (PWMF II EA)

Ontario Power Generation Inc. (OPG) proposes to develop the second phase of the Pickering Used Fuel Dry Storage (PUFDS) at the Pickering Nuclear Generating Station property in dry storage containers. As another part of the PWMF II, OPG plans to develop a Retube Components Storage Facility (RCSF) for future retubing of Pickering Nuclear Generating Station B in dry storage modules. SENES was retained to lead a multi-disciplinary team of environmental consulting firms to carry out the environmental assessment for the sixteen-month project that includes the preparation of an EA study report and all necessary supporting materials meeting the requirements of CEAA, for submission to the Canadian Nuclear Safety Commission. Other project areas include the provision of assistance with the selection of facility locations, and the identification environmental implications of associated with alternative sites. The environmental assessment includes review of atmospheric, aquatic and terrestrial environments; geology and seismicity; land use and sustainability; socio-economic, physical and cultural resources; radiation and radioactivity, risk and hazard assessment; cumulative effects assessments; and public consultation. *(Ontario Power Generation Nuclear)*

TECHNICAL REVIEW ON EIA OF ROMANIAN POWER REACTOR

SENES was retained by Export Development Canada (EDC) to conduct a review of Atomic Energy of Canada Limited's Environmental Impact Assessment (EIA) of Romania's Cernavoda Nuclear Power Plant – Unit 2. The review involved a three step process following the procedures outlined by EDC and involved comparison with Canadian and International practices. The review concluded that the EIA meets the requirements of EDC and is consistent with EA professional practice in Canada.

COMPREHENSIVE STUDY REPORT FOR WHITESHELL LABORATORIES DECOMMISSIONING, MANITOBA

The closure of research programs and operations at the Atomic Energy of Canada Limited (AECL) Whiteshell Laboratories required a change in the nature of the Atomic Energy Control Board (AECB) licence to reflect the transition from Site Operations to Site Decommissioning. The AECB determined that the decommissioning of the laboratories required a Comprehensive Study environmental assessment under the Canadian Environmental Assessment Act (CEAA). Decommissioning of the WR-1 nuclear reactor, was included in the project scope. SENES was retained by AECL to lead a multi-disciplinary team of environmental experts to prepare the Comprehensive Study Report for the proposed project. The study included an assessment of cumulative environmental effects. *(Atomic Energy Canada Limited)*

NATURALLY OCCURRING RADIOACTIVE MATERIAL (NORM)

SENES has successfully undertaken over 100 projects involving NORM. A partial listing of these projects which illustrates the wide scope of services related to NORM assessments is provided below.

NORM IN THE OIL/GAS INDUSTRY

The U.S. Environmental Protection Agency (EPA) prepared a preliminary risk assessment of management and disposal options for oil field wastes and piping contaminated with NORM in the state of Louisiana. SENES carried out a critical review of the EPA report which focussed on the validity of EPA's assumptions and the consistency of the assessment methodology with recognized risk assessment practices. *(American Petroleum Institute)*

Elevated levels of radium in produced water are adventitiously extracted from some oil wells, typically those associated with marine deposits. Radiation survey protocols used by the oil companies and the variability of radium concentrations provide for only small isolated areas of activity concentrations at less than 30 pCi/g in pipe scale and sludge. SENES used an estimated distribution of radium concentration in waste, and probabilistic methods for calculating potential doses from external gamma radiation and indoor radon to users of remediated oil field sites returned to unrestricted public access. (*American Petroleum Institute*)

REVIEW/DEVELOPMENT OF REGULATIONS

The U.S. Environmental Protection Agency (EPA) prepared a waste characterization and preliminary risk assessment of diffuse NORM mining wastes (i.e. large volumes of waste containing natural radioactivity at concentrations above background levels). A critical review of the EPA report focussed on the methodology used by EPA and the selection of models and parameter values used in the dose and risk assessment. *(American Mining Congress, now the National Mining Association)* The purpose of this study was to assist in the development of information on radon-222 in drinking water. Environmental levels and the pathways of exposure to humans were critically examined. The most recent dosimetric models on ingestion risk were reviewed while the inhalation risk was based on water-to-air transfer factors for various typical water uses and the best available epidemiological studies on the risks of exposure to radon and its progeny. A dynamic indoor air quality model was used to assist in the estimation of exposures. Several alternative rationales for the development of a risk-based guideline were presented. *(Health and Welfare Canada)*

The U.S. EPA introduced regulations requiring the reporting of the release of naturally occurring radionuclides in excess of reportable quantities (RQ) and supported the regulation with a Technical Background Document (TBD). SENES carried out a critical review of the radionuclide pathways and dose and risk models described and used by EPA in the TBD to establish the criteria levels (RQs). The review focussed on estimates of potential dose and risk resulting from releases of radon-222. *(American Mining Congress, now the National Mining Association)*

PHOSPHOGYPSUM (PG)

Phosphogypsum (PG), a by-product of the production of phosphate fertilizers, can contain several times the normal background concentrations of uranium series radionuclides, and may represent a radiation hazard under certain exposure scenarios.

The U.S. EPA prepared a waste characterization and preliminary risk assessment of emissions from storage piles and selected uses of PG. SENES carried out a critical review of the EPA report which focussed on EPA's methodology, the selection of models, and estimated doses and risks. *(The Fertilizer Institute)*

The U.S. Environmental Protection Agency prohibits by regulation the use of phosphogypsum containing radium-226 in excess of 10 pCi/g for road construction on the basis of their generic risk assessment and estimate of potential doses and

risks to workers and members of the public. SENES followed EPA's methodology and exposure pathways as closely as possible and estimated potential doses and risks to workers and members of the public from the use of phosphogypsum from stacks in Florida in a short experimental section of road. SENES demonstrated that potential lifetime risks were below the limit considered presumptively safe by EPA ($<10^{-4}$), and that the risk from phosphogypsum in the road was no greater than the corresponding risk should the phosphogypsum be left in the stacks. (*Florida Institute of Phosphate Research (FIPR)*)

This study examined the potential environmental and health concerns of PG stacks in Canada. The scope of the study included operating and decommissioned stacks, as well the use and mis-use of PG. Potential generic concerns relative to groundwater in the area of the stacks, as well the emission of radon and NORM-contaminated dust, were examined. Data from comparable PG sites in the United States were also reviewed in the study. Potential uses for PG that were studied included PG in non-residential construction and as a soil amendment. (*Environment Canada, Alberta Environment, Ontario Ministry of the Environment*)

The South African Council for Nuclear Safety (CNS) issued a guideline (LG-1032) which outlines the requirements for the assessment of radiation hazards to members of the public from mining and mineral processing facilities. SENES carried out the first assessment of this kind using the new CNS standard on the Kynoch Fertiliser plants at Potchestroom, Chloorkop and Phalaborwa. Thorium series radioactivity is present at higher than normal concentrations in the phosphate ore processed at the plant. A structured and comprehensive approach to the assessment involves the collection and review of existing data, the identification of critical receptors, screening level dose assessments, identification of additional sampling requirements, conduct of measurement programs and modelling exercises, and comparison of predicted potential doses and risks to nearby members of the public to regulatory standards. (*Kynoch Fertiliser (Pty) Ltd.)*

PG from a fertilizer plant in South Africa was treated off-site and used by others without restriction in the manufacture of cement, which

was shipped throughout the country. Feedstock to the fertilizer plant and the PG contained higher concentrations of NORM than found in surrounding soils. The Council for Nuclear Safety, the Nuclear regulatory agency, licensed the operation of the fertilizer plant and required that a risk assessment of potential exposures to workers and the public be carried out. SENES characterized the source of radioactivity in the PG and developed potential exposure pathways to workers and members of the public based on site-specific and generic data concerning the use of the PG. (*Kynoch Fertiliser (Pty) Limited*)

Construction of a proposed residential development in the vicinity of PG stacks in Calgary, Alberta was limited by a buffer zone that prohibited construction in the area. As part of an overall assessment of airborne emissions from the stacks, SENES evaluated the potential radiation exposures to future residents as a function of distance from the ponds. Partially as a result of this analysis, the buffer zone was reduced allowing the development to proceed. (*Douglasdale Estates*)

SENES prepared a series of annual air quality monitoring reports on airborne radioactive emissions associated with PG stacks in Calgary, Alberta, as well as provided on-going advice on the monitoring itself. *(Western Co-operative Fertilizers Limited)*

As part of the decommissioning plan for a phosphate fertilizer plant near Sarnia, Ontario, a radiation survey of the site and equipment was undertaken. Both external gamma measurements and contamination checks of equipment scheduled for potential re-use were undertaken, and compared to relevant release criteria for radioactive materials. (*ICI Canada Inc.*)

With the closure of the production activities at a phosphate fertilizer plant in Calgary, Alberta, SENES was retained to undertake a risk assessment of the preliminary site decommissioning plans which included three scenarios: current conditions, post-dewatering the stacks during reclamation, and post-reclamation. *(Western Co-operative Fertilizers Limited)*

ELEMENTAL PHOSPHORUS REFINERIES

A number of the major issues arising from an extensive decommissioning plan proposed for an elemental phosphorus refinery were NORM-related, namely, the short and long-term environmental implications of the proposed undertaking, and the potential occupational and public radiation exposures. Working in conjunction with the proponents, the potential exposures were evaluated, and presented in a number of meetings with both regulators and the public. Part of the analysis involved the selection of a radiation dose reference limit for workers who were not covered by any existing legislation on NORM-derived exposures. The analysis was accepted by the authorities and the involved citizenry allowing the decommissioning to proceed. (*Albright & Wilson Americas*)

Calcium silicate (phosphate "slag") is a hard ceramic-like material produced as a by-product in the production of elemental phosphorus from phosphate ore. The phosphate ore contains a low concentration of naturally occurring uranium which is retained in the silicates. The silicates have excellent properties as aggregate material. This study examined the potential radiation exposures and associated risks that might result from various proposed uses of the silicates, such as in roads, and parking lots. The risks were compared to levels of risks encountered through normal daily activities. *(Albright & Wilson Americas)*

As input to a risk assessment of an operating elemental phosphorus refinery in Soda Springs, Idaho, Classified as a Superfund site by the U.S. EPA, SENES performed a detailed analysis of the emission rates and dispersion of several types of air emissions from the refinery, including heavy metals, fluoride and NORM (naturally occurring radioactive materials). As a result of this analysis, which demonstrated that previous emissions and predicted air concentrations had been greatly overestimated, the air exposure pathway was relegated to a "non issue" in the final assessment of the refinery. (*The Monsanto Company*)

As part of an ongoing health and safety program, SENES was retained to assess the potential radiation exposures to workers from airborne radioactivity at an elemental phosphorus refinery in Newfoundland. A monitoring program using both persona and area monitoring devices, in combination with task-time analyses, was undertaken to estimate exposures to the radioactive dust. While the estimated exposures were within permissible levels for non-radiation workers or members of the public, recommendations to further lower potential exposures were made. (*ERCO Industries Limited, now Albright & Wilson Americas*)

During major maintenance and rebuilding of production furnaces at an electrothermal elemental phosphorus refinery in Newfoundland, a monitoring program was undertaken to assess the radiation exposures of workers. Gamma radiation exposures, total and respirable dust levels, radon concentrations and surface contamination levels were measured. Elevated beta radiation levels due to strongly affixed contamination (lead-210 and decay progeny) were measured on the interior furnace walls (carbon blocks) near the reaction zones in the furnaces. Total exposures were below permissible levels for non-radiation workers or members of the public. (*ERCO Industries Limited, now Albright & Wilson Americas*)

MANAGEMENT OF NORM WASTES

This study focussed on discrete sources of NORM wastes produced in Canada (as opposed to diffuse sources such as phosphogypsum), generally characterized by elevated, low volume non-uniform concentrations of NORM, such as pipe scale from oil and gas facilities and filters from phosphate

fertilizer production. Estimates of the volumes and generation rates of various waste types, identification of regulatory issues, and descriptions of current management practices were provided. The results of this study were to be used by the client in conjunction with the results of other studies to review and update the requirements for the management of low-level radioactive wastes in Canada. (*Low-Level Radioactive Waste Management Office*)

On behalf of the International Atomic Energy Agency (IAEA) and as part of an international team, SENES provided expert advice to the Government of Jordan on the environmental implications of NORM wastes produced by the phosphate industry. Several phosphate mining and fertilizer production facilities throughout Jordan were visited, and a summary report was prepared through the IAEA discussing potential environmental concerns and presenting suggestions for subsequent monitoring and analysis to be undertaken under the direction of the Jordanian government. (*International Atomic Energy Agency*)

Some of the heavy mineral ores and concentrates used in the production of titanium oxide contain NORM. SENES provided advice to two clients on the environmental and occupational implications of the resultant NORM-contaminated wastes, particularly in reference to the existing and proposed provincial regulations on the disposal of hazardous wastes. (*KRONOS Canada, Trioxide Canada*)

To assist in the management of NORM wastes from a titanium oxide producer that were classified as hazardous under Quebec regulations because of their radioactivity, the environmental and occupational implications of disposal in an industrial landfill were examined. The analysis examined task-time estimates for likely disposal scenarios, and considered potential exposure to gamma, radon and airborne dust. In the absence of applicable radiation exposure limits for non-nuclear workers, the estimated exposures were compared to a reference limit generally applicable to members of the public. (*KRONOS Canada*)

SENES carried out a critical review of a risk assessment prepared for the decommissioning of a site containing thorium contaminated slag in Surrey, British Columbia. (*Low-level Radioactive Waste Management Office*)

NORM AT RARE EARTH FACILITIES

Naturally occurring thorium series radionuclides contaminate a site in West Chicago resulting from past operations of a rare earth facility. One of the remedial activities planned during the cleanup involved washing and drying large volumes of soil to remove radioactivity. Radon gas would be released during these operations. SENES carried out an assessment of the magnitude of the release and the potential increase in normal background levels of radon in the vicinity. *(Kerr-McGee Chemical Corporation)*

Natural thorium contamination existed along the banks of a creek in a residential area of Chicago, due to past operations of a rare earth extraction facility. The U.S. Nuclear Regulatory Commission (NRC) ordered the present owners to show cause why the contaminated materials should not be cleaned up according to Environmental Protection Agency Standards that had originally been developed for uranium-bearing wastes. In response to the NRC, a study was carried out focussing on potential radiation pathways of exposure and the applicability of EPA standards. *(Kerr-McGee Chemical Corporation)*

NORM waste from a rare earth processing plant in New Jersey lay beneath an area proposed for residential development. SENES assessed the potential radiation exposures to residents should homes be built in the area, and developed statistical techniques to facilitate these predictions. *(Confidential Client)*

NORM IN MINING

A large smelter processing both ore and scrap metal and other materials for recycling had detected the presence of NORM in some special feeds and ingredients. Because of the potential implications of the NORM, SENES was retained to undertake a radiological survey of the smelter in order to assess any potential immediate hazards to workers. In addition, information on the radioactivity concentrations in the material to be processed at the smelter was reviewed, and potential occupational doses and risks were assessed. The findings were presented to both

management and worker representatives. The results and recommendations of the study were used by the company as a basis for updating the smelter policy on NORM. *(Confidential client)*

The potential problems associated with mining the Sarfartoq niobium deposit in West Greenland and the studies which would be required prior to the development of a mine were evaluated. This study was undertaken for the Mineral Resources Administration (MRA) for Greenland, based in Copenhagen, Denmark. The evaluation focussed on the potential environmental and safety problems associated with the radioactive constituents present in the Sarfartoq ore; it was largely based on a review of the proposed MRA study program and matters discussed at meetings with representatives from the Danish/Greenlandic Authorities in Copenhagen. (*Mineral Resources Administration for Greenland*)

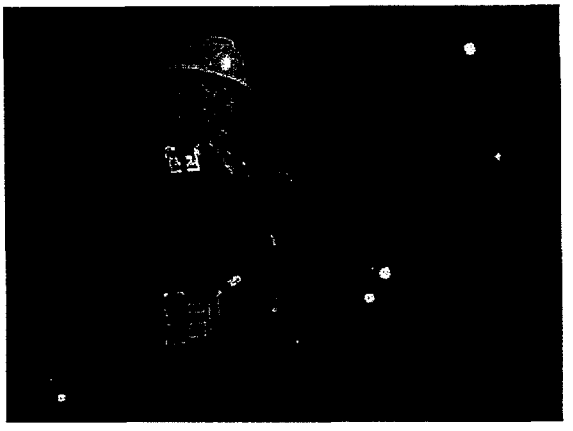
Niobium concentrate was found to contain elevated levels of NORM radionuclides from both the thorium and uranium series. Advice on transportation regulations and packaging requirements, including export requirements, were provided to the supplier for both domestic and international shipments. The supplier's clients were also advised on the regulatory and exposure implications of the NORM shipments. (*Cambior*)

Elevated levels of thorium-series radionuclides were present in deposits of beryllium ore scheduled for potential mining. The environmental and occupational implications of the NORM were assessed and presented to regulatory authorities as part of an overall review of the potential development. (*Hecla Resources*)

Iscor Mining are developing a mining and processing operation in KwaZulu-Natal province of South Africa to recover ilmenite from local surface deposits and produce titanium and high-purity iron.

The concentrations of naturally occurring uranium and thorium series radionuclides in the surface deposits are in excess of the criteria that require licensing by the national regulatory agency, the Council on Nuclear Safety (CNS). On behalf of Iscor, SENES prepared background and environmental assessments and submitted them to the CNS to demonstrate that potential radiological doses to members of the public from the proposed operations would be within regulatory limits. (*Iscor Mining*)

The radiological implications of the NORM to the operations of a tin smelter in Mexico where the tin was exported were evaluated. The evaluation was based on radiation measurements taken during a site visit to the smelter, a review of the potential occupational and environmental impacts of smelter operations, and an assessment of compliance with existing legislative requirements. (*Confidential Client*)



ABRASIVES

Abrasives and other ceramic materials were manufactured at a plant in southern Ontario using raw materials that contained higher than normal concentrations of uranium and thorium series radioactivity. Dust collection systems on the plant stacks removed most of the particulate emissions from the exhaust. SENES used measured dust emission rates, atmospheric dispersion models and environmental pathways models to estimate the radiological dose to members of the public in the vicinity of the plant from incidental radioactivity. *(Norton Advanced Ceramics of Canada Inc.)*

RADIOLOGICAL SURVEYS

SENES has performed numerous radiation monitoring studies for open areas, homes, buildings and industrial facilities. Many of these studies are confidential due to the sensitive nature of the work. and therefore cannot be described in open literature. A few examples are provided below.

IN-SITU LEACH IRRIGATION AREA

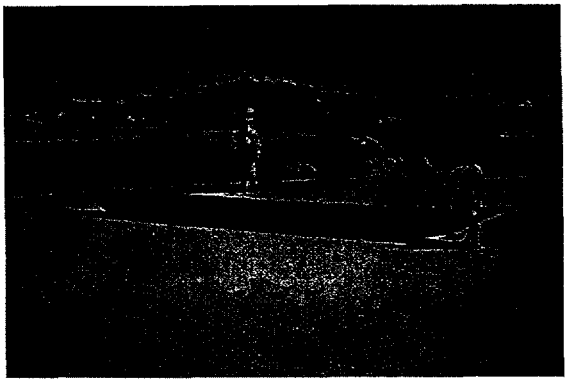
SENES provided a gamma radiation survey of more than 170 acres of in-situ uranium leach properties. Several 2" by 2" sodium iodide (NaI) detectors were mounted on a four-wheel drive vehicle and the gamma radiation levels were automatically merged with a real-time differential GPS providing co-ordinates at sub-metre accuracy. Gamma radiation levels were updated each second and, typically, 60 gamma radiation measurements were collected for each 100 m^2 surveyed. The gamma radiation measurements were summarized and presented as gamma radiation contour maps, as AutoCAD drawings and as summary tables. A relationship was developed between the depth profile of soil Ra-226 concentrations and the gamma radiation measurements. The relationship was used to estimate the volumes of material exceeding relevant criteria, and therefore requiring remediation, and to minimize the number of soil samples required to demonstrate compliance with the criteria. *(Everest Exploration Inc., Texas USA)*

PHOSPHATE SLAG

Phosphate slag had been used for a number of years in the construction of highways and streets, railroads, public parking areas, and as backfill in some residential areas of Quebec. Such uses were subsequently prohibited because of the NORM in slag. In this study, the resultant exposures were estimated using both measurement data and theoretical estimates based on the radiological characteristics of the slag and postulated exposure scenarios. The results were presented and discussed with public health officials who, in a subsequent study, generally agreed with the analysis in that they recommended that remediation efforts were not required because of the estimated magnitude of the risks and exposures relative to background levels. *(Albright & Wilson Americas)*

ENVIRONMENTAL BASELINE MONITORING FOR A DEVELOPING MINE IN MADAGASCAR

SENES undertook an intensive three-week baseline environmental monitoring program for a potential mine in southern Madagascar. The mining company required an evaluation of the existing radioactivity, air quality and noise and environments in the local communities that may be affected by the development. As part of the environmental monitoring program, gamma radiation exposure rate levels were measured at selected sites throughout the study area to document existing levels of gross gamma radiation from terrestrial sources. The purpose of this component of the monitoring program was to determine gamma radiation levels that could be used for future estimates of potential radiation exposure rates. In addition to the gamma surveys, radon and thoron samples were collected within the study area



NIOBIUM WASTE

A program of surface and subsurface gamma measurements and soil and water sampling was carried out to delineate the extent of niobium wastes containing elevated levels of natural thorium at an industrial site in Surrey, British Columbia. Through these investigations, the

extent of contamination was defined, the extent of the ground water transport was assessed, and the possibility of reducing the waste volume by segregating the contaminated material from non-contaminated soils was examined. The results of this program formed the basis for the design of the remedial work. *(Low-Level Radioactive Waste Management Office)*

RADIOLOGICAL CONDITIONS PERTAINING TO LOW-LEVEL SOIL CONTAMINATION, TORONTO

Summaries of radiological survey data were prepared to assist owners and tenants in their evaluation of an offer by the Ontario Ministry of Housing to purchase their homes. The Government of Ontario had offered to purchase properties in the residential subdivision in Metro Toronto where owners and Ontario Housing Commission tenants were concerned about the presence of low-level radioactive contamination in soil on their properties. Advice on the radiological conditions was provided to both the homeowners and the Ministry of Housing. *(Ontario Ministry of Housing)*

CLEAN UP OF LLRW FROM A SANITARY LANDFILL SITE

Surface soils at a sanitary landfill site were found to contain naturally occurring LLRW from a phosphate fertilizer plant. Radiation levels were measured across the site prior to the design and supervision of a program to remove the contaminated material. Radiation levels were again measured once remediation was complete to ensure that it had been effective. *(Canadian Industries Limited)*

MONITORING OF AIRBORNE PB-212:

Design of a monitoring program to U.S. Environmental Protection Agency (EPA) standards to measure thoron decay products (Pb-212) emitted during remediation of a site contaminated with natural thorium in West Chicago, Illinois. *(Kerr-McGee Chemical Corporation)*