Introduction

Uranium is a common element in nature, and has been used for centuries as a coloring agent in decorative glass and ceramics. Today, uranium has uses that range from metal alloys to aircraft counterweights. The most significant modern uses of uranium, however, have been for national defense and electric power generation. The advent of nuclear weapons and nuclear power in the United States resulted in a full-blown exploration and mining boom, starting immediately after World War II and making uranium the most important commodity in the mining industry. The greatest period of uranium production spanned from approximately 1948 to the early 1980s (U.S. DOE/EIA 1992). Through 2005, the industry had generated over 420,000 metric tons (MTs) of uranium to foster U.S. dominance in nuclear weapons technology, and later to feed the growing number of commercial power plants utilizing the enormous energy contained in the uranium nucleus (U.S. DOE/EIA 2003a, 2003b, 2006).

Another legacy of uranium exploration, mining, and ore processing was the creation of unreclaimed land workings wherever the uranium concentration in rock was either found or thought to be economically viable. Thousands of miners and prospectors, as well as large mining companies, searched the United States for veins, lenses, sedimentary deposits, and breccia pipes concentrating the valuable metal, echoing the California gold rush 100 years earlier. In many instances, they left behind unreclaimed and exposed wastes elevated in naturally occurring radioactive materials (uranium and its radioactive decay progeny), exposing people and the environment to its hazards.

In this report, Naturally Occurring Radioactive Material (NORM) is defined as: **Materials which may contain any of the primordial radionuclides or radioactive elements as they occur in nature, such as radium, uranium, thorium, potassium, and their radioactive decay products, that are undisturbed as a result of human activities.** Radiation levels presented by NORM are generally referred to as a component of "natural background radiation."

The term Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) is defined as: **Naturally occurring radioactive materials that have been concentrated or exposed to the accessible environment as a result of human activities such as manufacturing, mineral extraction, or water processing. "**Technologically Enhanced" means that the radiological, physical, and chemical properties of the radioactive material have been altered by having been processed (beneficiated) or disturbed in a way that increases the potential for human and/or environmental exposures. This definition differs somewhat from other definitions provided by the National Academy of Sciences (NAS 1999a) and the Conference of Radiation Control Protection Directors (CRCPD 2004) in that it further amplifies the need to include materials which have not been modified by human activities, yet have been disturbed in such ways that they can be misused by humans, or affect the environment[1]; it does not include a reference to Atomic Energy Act materials, as the definitions are changing (see Volume I and its Appendix VI). Uranium TENORM includes the succession of radioactive decay progeny of the parent uranium.

Under the Atomic Energy Act, the U.S. Nuclear Regulatory Commission (NRC) regulates operations that produce and concentrate uranium and thorium. In accordance with terminology of the Act, the NRC has defined in 10 CFR 40.4 "source materials" **as (1) uranium or thorium, or any combination thereof, in any physical or chemical form, or (2) ores which contain by weight one-twentieth of one percent (0.05%) or more of: (i) uranium, (ii) thorium or (iii) any combination thereof. Source material does not include special nuclear material.** It also defines the "by-product materials" (wastes) of those operations **as tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content, including discrete surface wastes resulting from uranium solution extraction processes.** Byproduct materials are also regulated by the NRC. Underground ore bodies depleted by such solution extraction operations do not constitute "byproduct material" within this definition. Wastes from conventional uranium mining (both surface and underground) are not subject to NRC regulation, but are considered to be TENORM, and thus subject to U.S. Environmental Protection Agency (EPA) and State agency oversight.

Under the Energy Policy Act of 2005, the Atomic Energy Act was amended to place additional discrete (highly radioactive in small, defined volumes) sources of TENORM which had the potential to pose a threat to public health and safety or the common defense and security under NRC jurisdiction. The definition of byproduct materials was further modified to include discrete sources of radium-226, any material made radioactive by use of a particle accelerator for use in a commercial, medical or research activity, or materials which might pose a similar threat to public health and safety or the common defense and security. Specific requirements were provided for determining the appropriate waste disposal methods for these materials which could possibly include uranium mill tailings impoundments. The NRC regulatory definition of byproduct materials to accommodate these amendments was finalized in late 2007 (U.S. NRC 2007a), to reflect the recent amendments. These products and wastes are not the subject of this report.

[1] The National Academy of Sciences (NAS 1999a) defined TENORM as "…any naturally occurring radioactive materials not subject to regulation under the Atomic Energy Act whose radionuclide concentrations or potential for human exposure have been increased above levels encountered in the natural state by human activities." The International Atomic Energy Agency (2003), although referring to this class of wastes and products as "NORMs", defined them as encompassing "all naturally occurring radioactive materials where human activities have increased the potential for exposure in comparison with the unaltered situation. Concentrations of radionuclides (i.e. TE-NORM) may or may not have been increased." Alternatively, the Conference of Radiation Control Program Directors (CRCPD 2004) has defined them as a naturally occurring radioactive material whose radionuclide concentrations are increased by or as a result of past or present human practices. TENORM does not include background radiation or the natural radioactivity of rocks or soils. TENORM does not include "source material" or "byproduct material" as both are defined in the Atomic Energy Act of 1954, as amended (AEA 42 USC §2011 *et seq.*) and relevant regulations implemented by the NRC. EPA believes the definition should include materials which were disturbed, but not further concentrated by human activities, so that the full scope of hazards from TENORM materials can be considered.

The U.S. Environmental Protection Agency (EPA) has previously issued reports on the uranium mining industry in response to congressional mandates and programmatic needs. In 1983, EPA published its *Report to Congress on the Potential Health and Environmental Hazards of Uranium Mine Wastes* (U.S. EPA 1983a, b, c), as required by the Uranium Mill Tailings Radiation Control Act of 1978. This study provided an important overview of the characteristics and generation of uranium mining TENORM wastes during a period when the uranium mining industry was still near its production peak. A subsequent 1985 *Report to Congress on Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale* (U.S. EPA 1985), carried out pursuant to requirements of the Resource Conservation and Recovery Act of 1976 (RCRA), as amended, provided additional risk information and characterization of uranium mining waste. In 1995, EPA issued the Technical Resource Document *Extraction and Beneficiation of Ores and Minerals: Uranium* as a technical update to provide a means of evaluating wastes that were exempt from or subject to regulation under RCRA (U.S. EPA 1995).

During the period 1989 to 1993, EPA worked on a draft scoping report (SC&A 1993) which compiled information on TENORM in several industries, including uranium mining. A preliminary risk assessment was also developed for certain public and occupational exposure scenarios involving the known radiation levels in those industries. Comments received on the draft from industry, as well as EPA's Science Advisory Board (SAB) (U.S. EPA 1994), resulted in further revisions of the scoping draft, though it was ultimately decided that a final report would not be issued.

Following a review of EPA's guidance for TENORM by the National Academy of Sciences, EPA's response to the NAS study, and discussions with EPA's Science Advisory Board, EPA's Radiation Protection Division decided that a further review of the current hazards associated with uranium mining TENORM was warranted. The SAB (U.S. EPA 2001a) agreed with EPA's intent to make TENORM documents useful to a broad audience, but also recommended that the whole life cycle of a TENORM source—in this case uranium extraction—be considered beyond regulatory or inter-agency considerations, and that the impacts of non-radiological contaminants also be examined in the Agency's technical reports. In addition to most sources of TENORM, EPA is responsible for setting environmental standards under the Uranium Mill Tailings Radiation Control Act, cleaning up hazardous waste sites that include some former uranium mines, and assisting Native Americans, including assisting in environmental reviews of proposed *in situ* leach (ISL) facilities. While this report focuses on the impacts associated with conventional surface and underground uranium mines, as a continuation of Volume I of this technical report (discussed below), and following the recommendations of the SAB, it provides limited background materials, in appendices, on risks associated with uranium milling and ISL operations and wastes generated by those processes, even though they may not be considered TENORM by virtue of their regulation by the NRC and its Agreement States under the Atomic Energy Act and its amendments.

The NRC stated its intent in July 2007 (NRC 2007b) to develop a Generic Environmental Impact Statement (GEIS) on uranium milling which would provide more detailed information on the ISL process and impacts, and may include more recent information on the impacts. The reader is referred to that document when made available to the public in the future for additional background information and associated risk assessment.

This is the second of two reports on uranium mining TENORM. The first report, *Technologically Enhanced Naturally Occurring Radioactive Materials from Uranium Mining, Volume 1: Mining and Reclamation Background* (U.S. EPA 2006a), provides background information on the occurrence of uranium, mining techniques, and reclamation of uranium mines. This report investigates the potential radiogenic cancer risks from abandoned uranium mines and evaluates which may pose the greatest hazards to members of the public and to the environment. The intent of this report is to identify who may be most likely to be exposed to wastes at small abandoned uranium mines, and where the greatest risks may lie. The specific wastes of EPA concern from this report and study are from abandoned conventional open-pit and underground uranium mines, and include overburden, unreclaimed sub-economic ores (protore), waste rock, core hole and drill cuttings, and mine and pit (or pit lake) water. All are described in Volume I of this study. In addition, EPA has compiled and published a uranium location database (U.S. EPA 2006b).

Additional information on uranium milling and extraction waste characteristics, and associated risks for uranium exposures used for this report was obtained from several sources, including industries, EPA contractors, previous EPA reports, federal, state and Tribal agencies, and scientific literature published by various national and international organizations. A first draft of this report underwent an outside peer review following the Agency's peer review process. Using the comments obtained, the report was updated and revised by including new appendices providing references and information on the risks associated with uranium mill operations and ISL operations. The revision was then provided to member agencies of the Interagency Steering Committee on Radiation Standards (ISCORS) Subcommittee on NORM, as well as other selected knowledgeable individuals and organizations, and placed on the EPA Internet site for public comment. Responding to reviewers' comments, we made some changes to the appendices.

While some of the thousands of conventional open surface and underground uranium mines in the United States have been reclaimed, many have not. Any mine may pose such hazards as open shafts and unstable supports (rock and wood), and contain gases, such as carbon dioxide and methane, that displace oxygen and could lead to asphyxiation. In addition to the immediate physical threats that abandoned mines may pose, exposure to radiation from uranium and radium and other contaminants in abandoned mine waste can increase a person's risk of cancer.

People are exposed to naturally occurring radioactive materials in soils, as well as natural occurrences of uranium in rock outcrops. However, the primary focus in this report is on exposures to those naturally occurring radioactive materials that have been enhanced by human activities at abandoned uranium mines. In examining the radiological risks due to mining, the focus is on those concentrations above natural background, as recommended in the EPA *Abandoned Mine Site Characterization and Cleanup Handbook* (U.S. EPA 2000a), with emphasis on uranium and radium. Abandoned conventional uranium mines may also contain other hazardous contaminants, such as metals. For example, the carcinogen arsenic may be a problem at some uranium mines, contributing to increased risks.

This scoping report describes in Chapter 1 several previous studies supporting the risk analysis, while Chapter 2 provides a geographic location analysis of uranium mines in the western United

States. Chapter 3 discusses potential scenarios and exposure pathways for the general public to hazards from uranium mines, describes the methodologies used in the analysis, and assesses cancer risks posed by human exposure to the various hazards from the mines. Chapter 4 examines the use of uranium risks in building materials, and Chapter 5 briefly discusses the potential for ecological impacts from the mines. Uncertainties and conclusions are presented in Chapters 6 and 7.