THE NATIONAL CENTER FOR RADIOECOLOGY (NCoRE): A NETWORK OF EXCELLENCE FOR ENVIRONMENTAL AND HUMAN RADIATION RISK REDUCTION

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ABSTRACT

Radioecology in the United States can be traced back to the early 1950s when small research programs were established to address the fate and effects of radionuclides released in the environment from activities at nuclear facilities. These programs focused primarily on local environmental effects, but global radioactive fallout from nuclear weapons testing and the potential for larger scale local releases of radioisotopes resulted in major concerns about the threat, not only to humans, but to other species and to ecosystems that support all life. These concerns were shared by other countries and it was quickly recognized that a multi-disciplinary approach would be required to address and understand the implications of anthropogenic radioactivity in the environment. The management, clean-up and long-term monitoring of legacy wastes at Department of Energy (DOE), Department of Defense (DOD), and Nuclear Regulatory Commission (NRC)-regulated facilities continues to be of concern as long as nuclear operations continue. Research conducted through radioecology programs provides the credible scientific data needed for decision-making purposes. The current status of radioecology programs in the United States are: fragmented with little coordination to identify national strategies and direct programs; suffering from a steadily decreasing funding base; soon to be hampered by closure of key infrastructure; hampered by aging and retiring workforce (loss of technical expertise); and in need of training of young scientists to ensure continuation of the science (no formal graduate education program in radioecology remaining in the U.S.). With these concerns in mind, the Savannah River National Laboratory (SRNL) took the lead to establish the National Center for Radioecology (NCoRE) as a network of excellence of the remaining radioecology expertise in the United States. As part of the NCoRE mission, scientists at SRNL are working with six key partner universities to re-establish a graduate education training program for radioecology. Recently, NCoRE hosted a workshop to identify the immediate needs for science-driven discoveries, tool development and the generation of scientific data to support the legislative decision-making process for remediation strategies, long-term monitoring of radiologically-contaminated sites and protection of human health and the environment. Some of the immediate strategic research needs were identified in the fields of functional genomics for determining low-dose effects, improved low-level dosimetry, and mixed (radiological and chemical) contaminant studies. Longer term strategic research and tool development areas included development of radioecology case study sites, comprehensive decision-making tools, consequence response actions, and optimized scenario based ecosystem modeling. A summary of the NCoRE workshop findings related to waste management needs and priority areas will be presented in this paper.

INTRODUCTION

Radioecology is a field of science that encompasses the relationships between ionizing radiation or radioactive substances and the environment, or subunits within the environment. These subunits may be populations, communities, ecosystems, biomes, or even the biosphere. The primary subdivisions of radioecology include: 1) Radionuclide movement within ecological systems and accumulation within specific ecosystem components such as soil, air, water, and biota; 2) Ionizing radiation effects on individual species, populations, communities, and ecosystems; and 3) Use of radionuclides and ionizing radiation in studies of structure and function of ecosystems and their component subsystem [1].

Why is Radioecology Important?

It is the science that describes the fundamental connections between environmental health and human health risks (Figure 1).

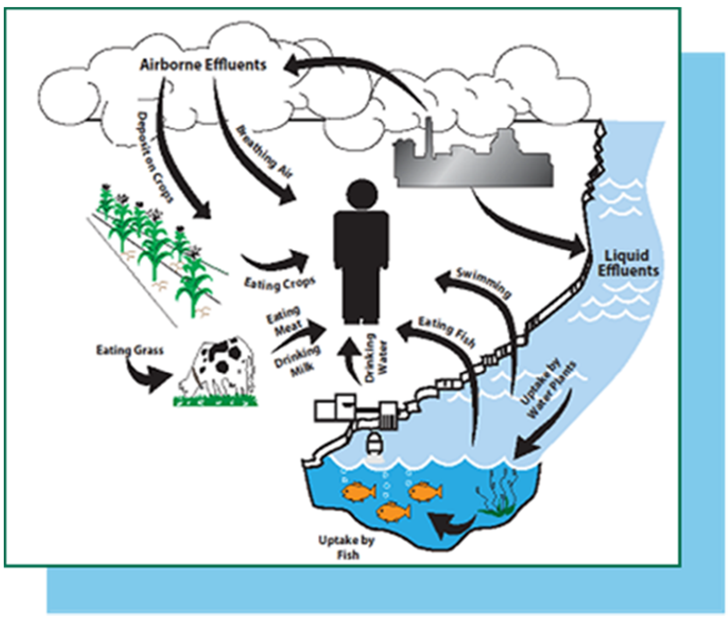

Fig. 1. Potential pathways of radionuclide movement through the environment.

There is a need for this scientific field to provide *credible, consistent, and defensible* information that can be used for cleanup activities and conducting risk assessments:

- Nuclear industry (new facility start-ups, small modular reactor developments, aging reactors, and other nuclear facility closures);
- Uranium mining and milling;
- Emergency response;
- Radioactive waste management;
- Environmental releases from nuclear facilities;

- Naturally occurring radionuclides in non-nuclear industries; and
- Education of the public about radiological risks.

Radioecology has provided the credible, consistent, and defensible basis for the successful and cost-effective environmental cleanup and closure of nuclear production and waste sites, such as DOE's Rocky Flats Plant, the Mound site, and others. For example, radioecology helped the DOE to determine the primary contaminants of concern, by evaluating nearly 8,000 radioactive and nonradioactive contaminants present at Rocky Flats during operational years, and then paring that list down to the two most important contributors to the dose and risk assessment calculations [2]. This saved DOE tens of millions of dollars in both the analyses and modeling that were needed to support the closure of that site. In addition, radioecology also provides the technical basis for making timely and reliable decisions on cleanup in the aftermath of nuclear incidents such as Chernobyl and Fukushima, as well as any potential "dirty bomb" scenarios taking place in urban settings.

Radioecology research provides the basis that will enable DOE to achieve successful closure of waste sites through development of sound science and applications required for efficient and cost effective closure.

Specifically, radioecology activities will:

- Provide the basis for defensible choices in making cost-effective remediation and long-term monitoring decisions;
- Provide for the development of credible data for assessing the site-specific impacts of specified radionuclides and performing accurate and reliable human health risk assessments;
- Provide a consistent and transparent approach for assessing the impact of waste site closures that the public, regulators, and other stakeholders can understand and will support; and
- Ensures that U.S. avoids unnecessarily conservative assumptions and practices, which could lead to costly solutions.

Current Status of Radioecology Programs

Most of the nationally funded radioecology programs that were established in the early 1950's have suffered reduced funding levels to the extent that most programs and research efforts in radioecology have come to a halt. The trickle-down effect of this reduction has been the subsequent reduction in graduate research programs and training to the extent that there are currently very limited graduate programs in radioecology in the United States. With the renewed and growing interest in nuclear energy and the continuing decommissioning and subsequent transitioning of legacy waste sites to long-term stewardship, there is now an immediate need to rebuild the pool of radioecology expertise.

The current status of radioecology programs in the United States find programs to be:

- Fragmented, with little coordination to identify national strategies and direct programs;
- Suffering from a steadily decreasing funding base;
- Hampered by the closing of key infrastructures and retirement of expertise; and
- Needing recruitment and opportunities to train new radioecologists to meet the needs of current and future nuclear industries and authorities.

Formation of the National Center for Radioecology (NCoRE)

NCoRE was formed by SRNL in 2010 to serve as the United States technical expertise on radioecology issues. Specifically, NCoRE will assist by:

- Serving as the technical lead for understanding the fate and effects of radionuclides released to the environment;
- Determining the environmental and human health risks associated with exposure to those radionuclides;
- Working with the nation's best radioecologists to prioritize research efforts to develop new knowledge to address the nation's needs for radioecology in areas such as nuclear industry and homeland security related issues; and
- Rebuilding radioecology programs, including DOE and graduate education programs, in the United States to ensure the long-term maintenance of expertise, infrastructures, and resources relating to radioecology.

SRNL signed Memorandum of Understanding/Memorandum's of Agreement with six Universities (Clemson, Colorado State, Oregon State, University of Georgia-Savannah River Ecology Laboratory and University of South Carolina) and two International Organizations (IRSN – France and International Radioecology Laboratory, Ukraine) to establish the framework for the center. These organizations were selected because of their strong history of academic programs and research in the field of radioecology.

Decision to Host National Workshop

As the resource of radioecology professionals has declined, the initiation of needed research needed to bridge knowledge gaps has also declined. In many cases, data and knowledge generated before 1980 still constitutes the primary knowledge base to support current decision making. While some of these data are still appropriate, advances in collection and analytical methods, as well as advances in understanding of the behavior of related chemicals in the environment, and their mechanisms of action on biological materials have not been addressed in the context of the behavior and effects of radionuclides in the environment. The absence of these advances is important because developing cleanup decisions for areas with multiple contaminants (i.e. radionuclides and chemicals) requires that a basic understanding of the driver of the risk (i.e. is it the radiation hazard or the chemical hazard) and the movement through the environment plays a critical role in cleanup decisions.

The idea for the a national workshop in radioecology came from the inaugural meeting of the NCoRE Key Partners held February 2011 in Neeses, South Carolina (Figure 2). At this meeting the partners agreed a workshop bringing together all of the remaining radioecology expertise in the field along with stakeholders and anyone interested in radioecology was needed to identify and prioritize national needs.

Fig. 2. NCoRE Key Partners at the inaugural meeting 2011.

DESCRIPTION

NCoRE National Workshop: Radioecology in the 21st Century

On August 15 and 16, 2012, NCoRE hosted the workshop entitled "Radioecology in the 21st Century - The Science, Tools, and Research Goals to Advance the Field." The objective of the two-day workshop, held at the Center for Hydrogen Research, in Aiken, South Carolina was to address: the current status of radioecology research programs in the U.S. and the immediate need for science driven discoveries, tool development and the generation of science data to support legislative decision making for remediation strategies, long-term monitoring of DOE sites, and protection of human health and the environment.

The workshop began with participants hearing from three speakers that discussed the status and needs of radioecology research from the perspective of radiological risk assessment (Dr. John Till, Radiological Assessment Corporation), needs through the International Commission on Radiological Protection (ICRP) (Dr. Kathy Higley, Oregon State University) and the status of programs historically maintained at a DOE site (Dr. Wendy Kuhne, Savannah River National Laboratory).

Participants were then asked to breakout into two discussion sessions focusing on science driven research and tool development topic areas (Table I). These were topic areas that were identified as needing further discussion by the NCoRE Key Partners. The workshop participants were asked to discuss and expand this list to generate a national priorities list. At the end of the breakout sessions the session leaders summarized results into major categories that would be used in the Radioecology Investment Allocation Exercise.

TABLE I. Topic areas for the breakout session at the radioecology workshop.

Science Drive Research	**Tool Development**
Translocation and uptake kinetic studies of "lesser studied" radionuclides.	Development of tools for assessment of site specific spatial transport and temporal geochemical cycling
Multi-contaminant effects	Development of rapidly deployable techniques and tools to mitigate widespread contamination of the environment
Radiation impacts on ecosystems	Development of reliable computational tools for estimation of radiological risk assessment
Chronic low level radiation impacts on ecosystems	Utilization of chemometric approaches to predict environmental behaviors of exotic radionuclides
Genomics based changes within radiation exposed and radionuclide-contaminated biota using state of the art analytical methods, such as transcriptome, proteome and metabolomics measurements,	Expansion of radioecological models to include kinetic predictions of movement (the goal is to reduce conservatism in assessment models and to take into account the effect non equilibrium conditions have on radionuclide uptake and transfer rates)
Radiation-induced epigenetic effects with a particular emphasis on the occurrence and magnitude of transgenerational effects	Incorporation of scaling and extrapolation methods (the goal is to maximize the availability of defensible data without having to conduct expensive research)
Enhanced dosimetry in experimental designs to accurately assess effects that may be slightly above or below background levels.	

Radioecology Investment Allocation Exercise

At registration, each of the Workshop participants was given a total of $100 "NCoRE bucks" (i.e., two $5s, two $10s, one $20 and one $50). The participants also completed a demographic form about their background including the following: Affiliation – Government, Academia, Industry or Other; Focus – Basic Research, Applied Research, Consulting, Regulatory, or Other; Discipline – Radioecology, Radiochemistry, Health Physics, Biology/Ecology, Chemistry, Physics, Engineering or Other.

On Day 2 of the workshop the participants were asked to spend their NCoRE Bucks on the categories identified. A total of seven categories were identified and these included the following:

- Functional Genomics,
- Improved Dosimetry,
- Mixed Contaminants,
- Case Study Sites,
- Data Source,
- Consequence Management, or
- Modeling.

DISCUSSION

A total of 61 participants attended the NCoRE Radioeology Workshop (Figure 3). The demographic distribution of participants attending the workshop represented the SRNL (44%), Universities (23%), Department of Energy (18%), SRS (8%), other Federal Agencies (4%), and Others (i.e. Non-Profits and Consulting Firms) (3%) (Figure 4).

Fig. 3. Participants attending the NCoRE Radioecology Workshop

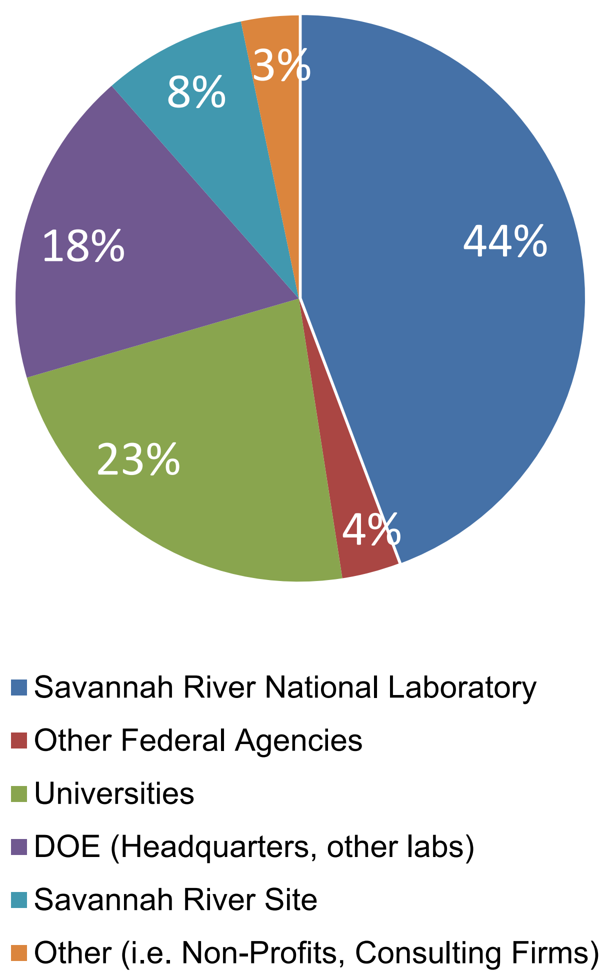

Fig. 4. Demographic distribution of participants.

A total of 31 participants used their NCoRE bucks in the investment exercise to prioritize the areas identified in the science driven and tool based discussion sessions. The participants identified the area of functional genomics as the highest priority area (Figure 5).

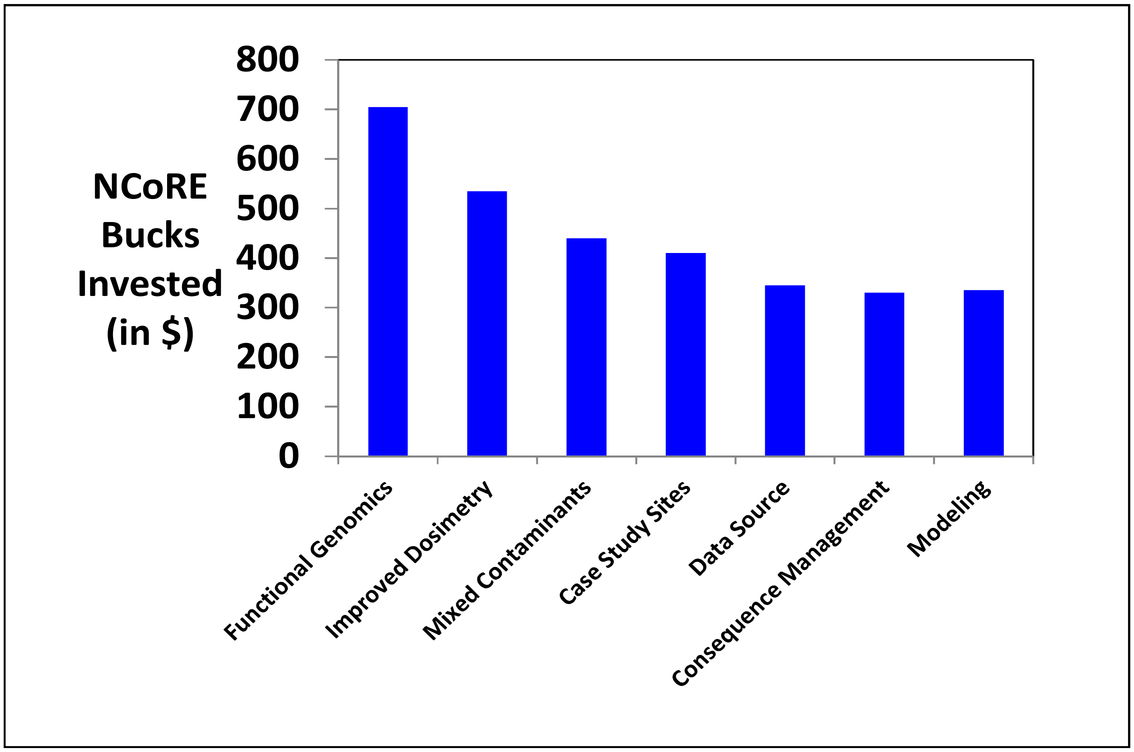

Fig. 5. Results of resource allocation investment exercise.

Functional Genomics

Functional genomics as defined in the workshop is an area of research that investigates effects from the molecular to individual and population level levels specifically for chronic exposure to low levels of radiation. The three primary issues that were discussed included: 1) how processes link effects from the molecular to the individual levels, 2) what are the trans-generational effects of exposure, and 3) what causes intra- and inter-species variation in sensitivity. There was widespread agreement that there are cutting edge molecular tools created for human medical research that have never been applied to radioecology research and non-model species. This area was considered the highest priority given the uncertainty that remains in understanding chronic low dose radiation following the Chernobyl nuclear power plant accident [3]. Utilizing a functional genomics approach could lend useful insight into effects following the Fukushima Dai-Ichi accident.

A functional genomics approach should be used to examine how radiation impacts genes, chromosomes, RNA, and proteins to begin to understand the relationship between the genome, biological function, and phenotype. The first step is an integrated study that uses controlled experimental exposures of several species and simultaneously measures molecular and individual effects. The goal is to understand whether exposure alters the phenotype in a way that affects growth, survival, and/or reproduction and if so to assess the underlying changes in the genome that caused the phenotypic response.

One of the next steps is to expand the breadth of species examined with a comparative approach to better understand what causes interspecific variation in sensitivity. Additionally, multigenerational exposure studies should be incorporated to not only better understand individual level effects but to begin linking effects to the population level. Finally, a decision was made to focus on species that have been the subject of studies on non-radionuclide stressors. Given that radionuclides almost always are found in conjunction with other stressors it would be a strong approach to choose species for which some information on other stressors is available. This will make future studies of combined stressors more informative.

Improved Dosimetry

Improved dosimetry in non-human biota studies ranked second in priority. It was agreed upon by the participants that a recognized data gap in understanding effects and the impact of chronic low dose radiation exposure on non-human biota is the lack of dosimetric data. External dosimetry is often used in non-human biota experiments because it is considered easier but it neglects the contribution of internal exposures. External dosimetry has its own challenges because of the need for new and better designs for physical dosimeters that can be attached to biota of varying body shapes, sizes, lifestyles and habitats. Improvements in internal dose measurements and data are needed to support dosimetric models currently utilized by the International Commission on Radiological Protection (ICRP) to develop a framework for protection of the environment and non-human biota [4,5] .

Radioecology Case Study Sites

The participants strongly supported the use of sites with existing contamination and baseline data as case study sites. This would provide the most defensible information on radioecological impacts in real environments and ecosystems. Further, the participants indicated that such sites provide opportunities to generate the information cost effectively and relatively rapidly. The example sites proposed by the participants include DOE facilities such as SRS and ORNL (with baseline information beginning in the mid-20th century, tabulated information on radionuclide releases, and significant monitoring of radionuclides and ecological conditions near facilities and waste disposal areas by multiple organizations continuously since that time) [6], accident sites (e.g., Fukushima), mining and milling sites, etc. The participants suggested that case study sites could provide a unique opportunity to determine if advancing scientific techniques such as genetic markers represent a path toward significantly simplifying radioecology by representing a more direct measure of the composite impacts with the complexities already accounted. The case study sites also could represent locations for the evaluation of existing/or novel remediation technologies.

Comprehensive-Authoritative Data Source to Support Radioecology

This would include several activities: a) compilations of reviewed-consensus transfer and dose factors, b) monitoring networks to provide baseline information across North America, c) organized-checked-accessible data from available characterization studies and the monitoring networks. The participants advocated incorporating biogeochemical influences into the transfer factors (e.g., biotic ligand models and competitive uptake of Ca-Sr). Current North American data sources (e.g., Risk Analysis, Communication, Evaluation, and Reduction, RACER) focus primarily on human health and investment in this strategic category would encourage and advance efficient and defensible radioecology assessments and would extend the information being assembled in Europe (e.g., by the Strategy for Allied Radioecology network of excellence

(STAR) and support organizations such as ICRP in developing policies and guidelines. The participants indicated that investment in "better" standardized tools for measuring low environmental levels of radionuclides will be needed to support this strategic category.

Example of current/emerging information and tools coupled to this category: RACER, Environmental Protection Agency (EPA) atmospheric deposition program, national uranium resource evaluation (NURE) database, EPA Integrated Risk Information System (IRIS) database, ICRP Committee 5 information and tools, BIOPROTA & STAR Consortium information and tools from Europe, statistical models, EPA Guidance on natural attenuation of metals and radionuclides and the associated Department Of Energy (DOE) /Interstate Technology Regulatory Council (ITRC) developed scenarios. Some of the key information supporting this strategic category includes the results/products generated by research from the genetics and dose estimation strategic categories.

Consequence Management Tools for Response, Remediation and Restoration

Consequence management would focus on compilations of available technologies for: a) rapid response (generally simple-direct-deployable methods for accident scenarios), b) longer term removal, immobilization or detoxification, and c) restoration (e.g., including radiation and toxic recovery as in mining). As with the Data Source category, the focus would be on generating authoritative compilations. The information would include selection criteria/matrices, guidelines, and lessons learned. This effort would augment and advance existing systems such as Radiation Emergency Assistance Center / Training Site (REAC/TS), for radioactive emergencies.

Example of current/emerging information and tools coupled to this category: REAC/TS, DOE/EPA/DoD research on cleanup technologies (development, demonstration, deployment, testing, lessons learned), ICRP Committee 5 information and tools, BIOPROTA & STAR Consortium information and tools from Europe.

Optimized Scenario Based Ecosystem Modeling

This effort would focus on developing practical models to assess radiological impacts of releases from existing nuclear facilities and disposal areas, planned facilities, or accidents/emergencies. The breakout group emphasized paradigms to incorporate key complexities while keeping the modeling tools useable. Example complexities included: seasonality and temporal variability in some settings (e.g., wetlands), estimating dose in a real-world setting with patchy radionuclide distributions, chemical speciation and facilitated transport, ecosystem feedback loops, etc. The suggested paradigms included conditional parameters (e.g. transfer factors), which are often scenario based (e.g., based on biogeochemical master variables such as pH, Eh, water content, ionic strength, temperature, … or on energy flows) and binned, where possible, into a simplified usable format. In general, the consensus was better linking of biogeochemical models to radioecology models with sensitivity analysis and input/output that would support decision makers.

The participants discussed the challenge of "metrics" in radioecology and felt that this would be an important component of improved modeling. For example, should an index or indicators of overall ecosystem function/health/services/damage be the key metric(s), or should multigenerational reproductive success related to dose for representative, local, sensitive, critical and/or threatened/endangered species be used? In some of these cases, generating the necessary radiological effects information will be challenging and expensive. The participants indicated needs for regional specific overlays (e.g., different sources/types of food – equivalent to the western diet versus the eastern diet in human risk assessment). The participants recommend a focus on scaling and extrapolation and using analogs where possible. The participants felt that incorporating advancements in understanding key ecosystem compartments s needed -- such as the hyporheic zone ("ground water-surface water interface") seawater, and aquatic sediments as well as compartments where radionuclides would concentrate such as biofilms and upper tropic levels. The participants indicated that models will need to consider a broad list of contaminants given the diversity of release situations (ranging from reactor accidents to releases from disposed waste) and should include impacts of co-contaminants or complex mixtures of contaminants as needed.

Example of current/emerging information and tools coupled to this category: Environmental Risk from Ionizing Contaminants: Assessment and Management (ERICA) dose rate tool, ICRP Committee 5 information and tools, BIOPROTA & STAR Consortium information and tools from Europe, ASCEM and other (coupled) biogeochemical models, bioenergetics models, hydrodynamic models, statistical models, EPA Guidance on natural attenuation of metals and radionuclides and the associated DOE/ITRC developed scenarios. Some of the key advances in this strategic category are expected to derive from the results/products generated by research from the genetics and dose estimation strategic categories and the modeling improvements and optimizations would be enhanced by the Data Source development strategic category.

CONCLUSIONS

There is a significant opportunity to advance the field of radioecology by applying some of the latest scientific tools and advances (such as genomics, proteomics, voxel phantom development and remediation technologies) to provide valuable information to support the safe operation, closure of existing nuclear facilities and support the development of new facilities. Activities in radioecology will:

- Provide the basis for defensible choices in making cost-effective remediation and long-term monitoring decisions;
- Provide for the development of credible data for assessing the site-specific impacts of specified radionuclides and performing accurate and reliable human health risk assessments;
- Provide a consistent transparent approach for assessing the impact of waste site closures that the public, regulators, and other stakeholders can understand and will support; and
- Ensures that U.S. avoids unnecessarily conservative assumptions and practices, which could lead to costly solutions.

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