Radioactivity in the Ocean, 5 decades later (RiO5)

Working Group proposal to the Scientific Committee on Oceanic Research (SCOR)

Summary Abstract

Over the past 50 years, natural and anthropogenic radionuclides have been instrumental in addressing many important questions in oceanographic research. Yet knowledge gaps remain regarding their spatial and depth distributions and the temporal evolution of many radionuclides of importance to both oceanographic and human health issues. The Fukushima Dai-ichi disaster has also recently heightened public and policy concerns related to the human health effects of radioactivity attributable to external exposure from ocean contact and internal exposure from seafood consumption. The timing is thus right for a new SCOR Working group- "Radioactivity in the Ocean, 5 decades later". The goals of RiO5 are to synthesize in a series of papers, the latest scientific insights that have been gained from new global databases on natural and artificial radionuclide distributions, and to identify gaps in our current understanding and scientific knowledge of marine radionuclides. We also plan to create an online compilation of papers and lectures related to radioactivity in the marine environment that will assist in the education and training of the next generation of marine radiochemists and radioecologists. At the same time, we will develop tools to enhance public understanding of radioactivity. Finally, we will assist in the organization of an international symposium that would bring together academic, nuclear power industry and national laboratory experts working in this area.

Scientific Background and Rationale

The very first SCOR Working Group #1, entitled Radioactivity in the Ocean, was formed in 1958 and met in 1959. Chaired by the Japanese scientist, Dr. Yasuo Miyake, the primary objectives of WG1 were to standardize and improve analytical methods and coordinate world-wide measurements of artificial radioactivity. Indeed, when referring to radioactivity, most still focus on the immediate detrimental impacts of anthropogenic radiation and issues related to contamination. Yet since that time, there has been considerable advancement in the field of marine radioactivity, not only in the measurement and application of artificial radionuclides, but also of cosmogenic and U-Th series radionuclides to study ocean processes. Several SCOR WGs have taken advantage of these advances, such as in the use of thorium-234 as a particle export tracer (WG#116) and radium isotopes in the study of submarine groundwater discharge (WG#112). Many other radionuclides are instrumental in geochronology (^{210}Pb, ^{14}C, ^{137}Cs) or in studies on present and past ocean circulation (^{3}H, ^{129}I, ^{230}Th/^{231}Pa). Regardless of the application, it is necessary to understand: i) the evolution of radionuclide sources (both natural and anthropogenic) over a range of temporal and spatial scales, ii) how to use their inherent geochemistries and decay rates to answer a wide range of oceanographic questions and iii) the potential human health effects of radionuclides in the marine environment.

We propose a SCOR Working Group to look at Radioactivity in the Ocean, 5 decades later (RiO5). RiO5 would provide a comprehensive evaluation of our current knowledge of radioactivity in marine systems. RiO5 would be comprised of an international consortium of radiochemists and ecologists whose major focus will be on increasing scientific and public understanding of the sources, fate, and applications of natural and artificial radionuclides in marine systems. This will be accomplished through updating and improving access to radionuclide databases, providing a synthesis and review of radionuclide distributions, and developing a strategic plan for filling missing knowledge gaps.

The timing is right for RiO5 for many reasons. In the aftermath of the Fukushima Dai-ichi disaster – and after years of relative complacency – the public and policymakers have new, heightened concerns about radioactive contamination and potential human health concerns. We are also still limited by where radioactive wastes may be stored, due to perceived and real threats to environmental safety. Nuclear-fueled ships and submarines ply our oceans. The number of nuclear power plants worldwide (>430) is expanding in many countries and is likely to continue as we replace other forms of power that produce greenhouse gases. There are continued concerns regarding the spread of nuclear weapons and "dirty" bombs. Yet, at the same time, Cold War-era nuclear scientists and radiochemists have retired, creating a need for training the next generation of marine radiochemists and radioecologists. As this is happening, a new global view of natural and artificial radionuclides is emerging through programs such as the SCOR sponsored international GEOTRACES program. Although the isotopes measured by GEOTRACES are a limited set, this is the first such effort since the GEOSECS Program that mapped several radionuclide distributions in the oceans in the 1970's. Indeed, the time elapsed between both major efforts appear as a unique opportunity to examine not only how specific radionuclide inventories have changed, but what those inventory changes mean with regards to their marine geochemistry and implications for global biogeochemical cycles (e.g., Moore et al., 2014).

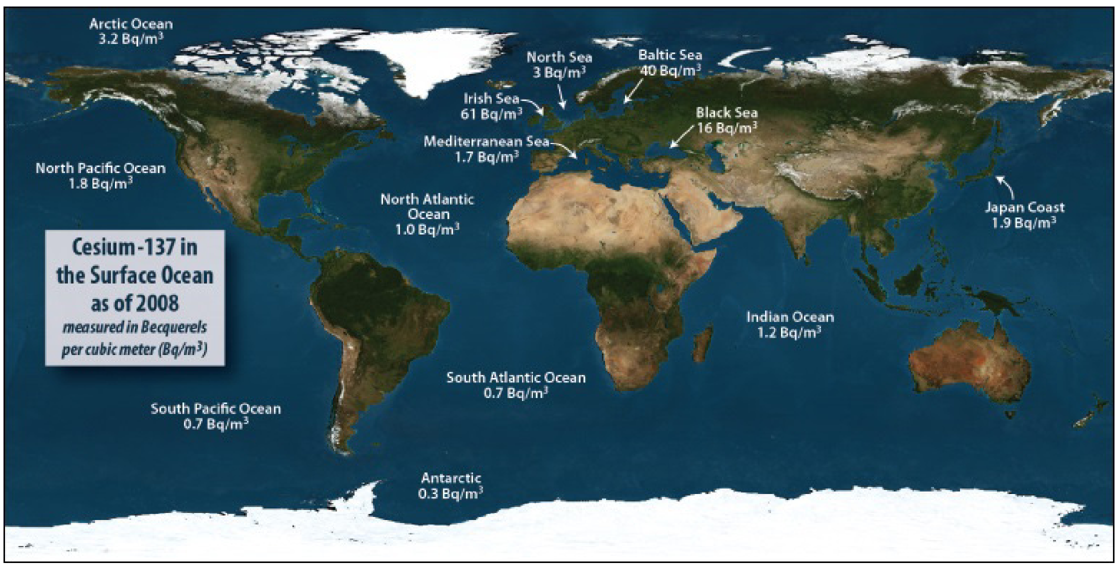

Figure 1. Example of recent compendium of ^{137}Cs activities in marine systems prior to the Fukushima accident. Data source: http://maris.iaea.org Available at: http://ourradioactiveocean.org

One example of the value of such a review of current knowledge is shown here by summarizing the global distribution of ^{137}Cs in the surface ocean (Figure 1). One can immediately observe the following: 1) 1960's fallout ^{137}Cs is rather uniform globally, with slightly higher values in the Northern Hemisphere (due to location of weapons testing) at background levels of 1-2 Bq m^{-3}; 2) higher levels from Chernobyl fallout in the Baltic and Black Seas (20-40 Bq m^{-3}); and 3) perhaps the most surprising, or at least less well known, is that the Irish Sea still maintains the highest ^{137}Cs levels in the ocean due to prior nuclear fuel reprocessing releases from Sellafield. This map further enables the establishment of a baseline for oceanic ^{137}Cs activities prior to Fukushima. In contrast to these levels, ^{137}Cs in the ocean peaked at over 50,000,000 Bq m^{-3} close to the reactors in April 2011 (Buesseler et al., 2012), which was of direct concern to human health and marine biota, and far higher than the concentrations observed after weapons testing or the Chernobyl accident. Three years later, the public remains concerned about the predicted ^{137}Cs activities of 10-30 Bq m^{-3} within the Fukushima plume approaching the west coast of

North America (Rossi et al., 2013). However, these predicted activities are in fact lower than that found today in some of the world's oceans and should not cause any measureable impact on human health. Compilations of global baselines such as that shown in Figure 1 are clearly necessary and allow for such assessments to be made. This and other maps are part of the first steps of RiO5.

Figure 2 is an exciting example of a natural radionuclide data set only recently available online as part of the GEOTRACES Program. While variable and high dissolved ^{210}Pb activities in surface waters are expected due to atmospheric inputs, high activities of ^{210}Pb at depth not only suggest substantial remineralization of sinking particles, but an additional source of ^{210}Pb that has not been previously observed (using mass balance). Such profiles therefore demonstrate how ^{210}Pb may be used to examine sources and cycling of other stable trace elements of similar particle reactivity that are more difficult to assess from their concentrations in seawater.

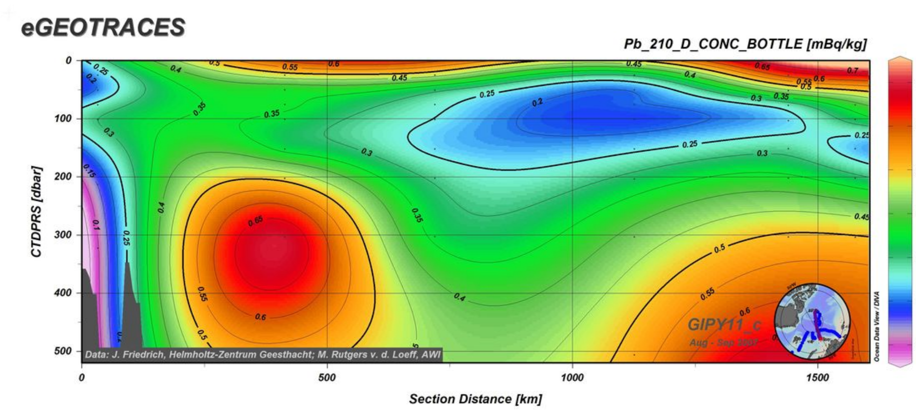

Figure 2. Example of radionuclide data available online as part of the GEOTRACES Program. Data source http://www.egeotraces.org/

A final example showing the strength of pairing natural and artificial radionuclides is from Charette et al. (2014), who used ^{224}Ra as an indicator of coastal water ages (time since contact with sediments and/or groundwater) and found that in samples collected in 2013, the activities of ^{137}Cs near the coast of Japan remained higher than those offshore, similar to ^{224}Ra. Using a mass balance approach they estimated that continued release of ^{137}Cs from the Fukushima NPP site must be occurring (9 GBq per day), a key unknown in the ongoing evaluation of Fukushima ocean impacts.

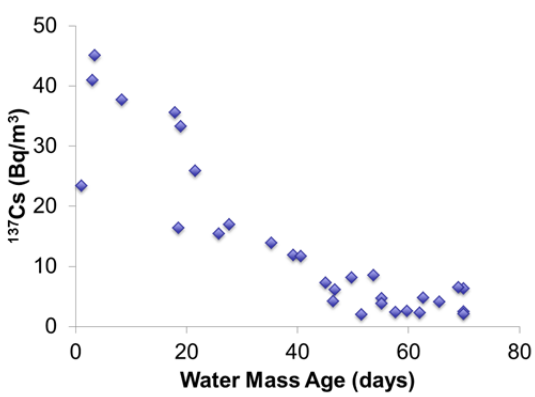

Figure 3. Plot of water mass age derived using ^{224}Ra versus ^{137}Cs activity off the coast of Japan. Source: Charette et al., 2014

These examples illustrate the breadth of new insights obtainable by synthesizing current radionuclide data sets (Figure 1); exploring new features in global transects (Figure 2); and combining studies that include both natural and artificial radionuclides (Figure 3). In addition, tremendous technological developments over the past decade have enabled the measurement of natural and artificial radionuclides at previously unattainable levels. This has revolutionized the radiochemistry field and has been instrumental in discovering new applications of radionuclides to address many important questions in oceanographic research.

RiO5 will bring experts together to review the current knowledge of radioactivity in marine systems and explore and identify research areas where new uses of radionuclides as tracers will be instrumental. These processes include: 1) understanding the global ocean carbon cycle with regards to sources of carbon to marine systems (gas exchange, riverine and ground water, hydrothermal vents, etc.) , *in situ* cycling (nutrient turnover), the transport of material from the surface ocean to depth (biological pump-mediated particle export and remineralization), and burial in marine sediments (months to millennia); 2) understanding ocean circulation in current and paleo climates from coastal ocean currents to large-scale tele-connections between various ocean basins; and 3) understanding contaminant sources, transport and removal of not only the radionuclides themselves, but other elements of similar chemistries, such as bioactive and particle reactive trace elements measured in the GEOTRACES program, some of which have their own pollution concerns (Pb, Hg, Cu, etc.).

Terms of Reference

We propose that SCOR establish a working group called "Radioactivity in the Ocean, 5 decades later (RiO5)" with the following terms of reference:

1. Combine and build upon existing global and individual databases of natural and artificial radionuclide distributions to make an user friendly and easily accessible on line product;
2. Summarize and publish review papers on these global radionuclide datasets and provide examples of how these can help improve our understanding of ocean processes and contaminant fate and transport;
3. Identify gaps in scientific knowledge in relation to radioactivity in the marine environment;
4. Bring together academic, nuclear industry and national laboratory expertise for an international symposium on radionuclides in the ocean;
5. Provide a warehouse of education materials to assist in the education and training of the next generation of marine radiochemists and radioecologists;
6. Develop tools to enhance public understanding of radioactivity, in particular in the ocean.

These activities would be achieved by convening WG meetings (1 per year for 3 years), exchanges among WG Members, building web-based informational resources, writing scientific manuscripts, and finding resources and partners for hosting a large international symposium.

Working plan

This Working Group is envisioned as a three-year activity that we hope will have a legacy beyond the funded study, to create a trusted resource for the ocean sciences and environmental community on matters related to radioactive substances, sources, and wastes in the oceans. The time-line delineated below outlines the major steps and their order to reach the deliverables (see below) according to the defined terms of reference. The timeline does not include much of the between-meeting activities and communications that are important to keep the WG going, which will be the responsibility of the two co-chairs to maintain.

Year 1

WG meeting #1- hosted by M. Dai, Xiamen U. (partial financial support in place through Xiamen U.). In conjunction with WG meeting, a two-day training workshop will be considered as part of the WG capacity building efforts (see Capacity Building below).

- Charge to WG participants- gather information on existing and ongoing radionuclide data bases, such as Marine Information System (MARiS) (IAEA- Morris lead), HAM (Japan- Aoyama lead) and GEOTRACES (Schlitzer Associate Member lead). Use Ocean Data View tools for visualization and use these data to develop global distribution maps (see Figure 2 as example)
- Outline synthetic papers to present the current state of the global oceans for natural and artificial radionuclides, based on the combined datasets achieved above. Spatial distributions and evolution as well as a global overview of potential risk will be the focus of the artificial radionuclide datasets, while objectives for naturally occurring radionuclides include their relevancy with regards to applications and newly available tools
- Discuss challenges and frontiers in marine radiochemistry and radioecology
- Discuss plans for WG web site and how to expand and build and disseminate education materials for public and students. Use WHOI's Center for Marine and Environmental Radioactivity site as host and model of similar activities (http://www.whoi.edu/cmer ; web site costs supported by CMER)
- Introduce plans for an international symposium on marine radioactivity. Decades ago, similar efforts were hosted by UK (MAFF) and French (IRSN) ministries in Cherbourg in 1996 (Radionuclides: a tool in Oceanography 1987; Radionuclides in the Ocean- RADOC 96). IAEA has been approached to help support and host the symposium and welcomes additional discussion upon SCOR funding of this WG

Year 2

WG meeting #2- hosted by K. Buesseler (WHOI meeting facilities support in place); possible alternative is to hold in conjunction with international meeting such as Ocean Sciences to increase participation by Associate Members.

- Review progress done on the database efforts
- Review synthesis papers and prepare for publication
- Develop list of future challenge and areas of need
- Planning for international symposium on Radionuclides in the Ocean, including promotion and organizing co-sponsorship
- Review education and public outreach materials and discuss submission of e-lectures, fact brochures, hands on activities for primary and secondary education and coordinating ongoing hands-on training by various international groups of the next generation of radiochemists

Year 3

WG meeting #3- in conjunction with international symposium.

- International Symposium- collect extended abstracts & manuscripts
- Post conference publication/book and organize associated papers in open access format such as a **Frontiers Research Topic** (http://www.frontiersin.org/blog/What_is_a_Frontiers_Research_Topic_/620)
- Final preparation of wide release of educational materials- for both student and public audiences

Deliverables

1. Connect all available data bases via the IAEA's MARiS portal, including data collected via the GEOTRACES and HAM data bases and individual studies. MARiS is a publicly accessible database in the same spirit embraced by GEOTRACES (http://www.egeotraces.org/) and various time-series programs (HOT (http://hahana.soest.hawaii.edu/hot/hot-dogs/interface.html), PAPA (http://oceanobservatories.org/infrastructure/ooi-station-map/station-papa/), etc.) (WG Members lead: Morris, Aoyama, Masque; Associate Member: Schlitzer)

2. Review papers on ocean radionuclide distributions and future challenges in their measurement and application. (All WG Members)

3. Production of education tools at the primary school, undergraduate, and graduate level. This includes eLectures (http://www.aslo.org/lectures/), online course materials based on courses already being taught by SCOR WG Members (e.g. Johnson, 2014)

4. Public communication and dissemination (web tools and fact sheets) that include basic information on radiation literacy and marine radioactivity using lessons learned from Fukushima to motivate and attract attention (see example at http://www.ourradioactiveocean.org/) (WG Members lead: Benitez-Nelson, Masqué, Buesseler; Associate Member: Johnson)

5. International symposium in year 3 - Radionuclides and Marine Processes – attended by academia, industry, national laboratories, with published scientific abstracts, following the model of the MARC Applications of Radioanalytical Chemistry Conferences. Seek partnership with IAEA (WG Member- Morris) and other EU sponsors (WG Members lead: Oughton, Charmasson, Delfanti) and US private foundations (WG Members lead: Buesseler, Benitez-Nelson)

Capacity Building

Members will participate individually and collectively in efforts to increase public and scientific understanding of marine radioactivity and radioecology. This SCOR WG will seek financial support as needed from the national agencies of WG Members, international organizations like the IAEA and IOC/UNESCO and groups such as, IUR, etc. and private funding sources. By developing tools for web based training, the next generation of graduate students will be exposed more readily to the concepts needed to understand radioactivity and radioecology in the marine environment. By increasing interactions among WG Members and knowledge of national programs, student exchanges and mentoring and sampling opportunities will be enhanced. With web-based sources to promote public understanding about radioactivity and open-access publication of synthesis papers and symposium volumes, there will be new resources to help expand the field and provide information to the public and policy makers.

Activities will include the web-based education materials and documents as well as online courses explained above. But more specifically, RiO5 will also work to-

- Coordinate short term training of both junior and senior researchers at WG Member laboratories
- Facilitate participation of young researchers in oceanographic cruises to be trained in sampling and analyses
- Seek and facilitate appropriate ways of funding for young researchers, for attending research conferences, short-term stays at research centers or PhD or postdoc fellowships
- Approach the IAEA for Technical Cooperation for developing countries. Some of RiO5 Members already collaborate with the IAEA on this and the WG can work with the IAEA to identify future requirements for capacity building
- Pursue capacity building for developing country scientists through participation of developing country scientists in WG, holding first meeting in China in conjunction with a two-day training workshop, and seeking assistance from SCOR to involve participation of developing country scientists in WG activities
- Routine activities of outreach activities are also anticipated through national and regional user groups, such as COSEE China (China Ocean Science Education Excellence Partnership) which is officed at Xiamen U.

Working Group Members

Full Members of this Working Group were selected based upon their scientific contributions, participation in educational activities, leadership as evidenced by participation and chairing national and international committees and symposium, editorships, career awards and recognition, experience in launching new initiatives and a willingness to participate in public and policy discussions on important issues related to marine radioactivity and radioecology. Proposed WG Members were also chosen to be widely representative of international expertise in the field and to span a range of skills and knowledge in marine radiochemistry and radioecology. Associate Members were considered important to expanding that scientific and regional expertise, and will be invited when possible to join us at WG meetings and will be called upon between meetings to assist with specific WG deliverables, as needed.

Full Members

Name	Gender	Place of Work	Expertise
Ken Buesseler*	M	WHOI, USA	Marine radiochemistry, C cycle, public education, GEOTRACES
Minhan Dai*	M	Xiamen U., China	Coastal biogeochemistry, radionuclide applications, GEOTRACES
Michio Aoyama	M	Fukushima U., Japan	Marine radiochemistry, global nutrient cycling
Claudia Benitez-Nelson	F	U. So. Carolina, USA	Marine radiochemistry, methods and teaching

Sabine Charmasson	F	IRSN, France	Radioecology of natural and artificial radionuclides
Roberta Delfanti	F	ENEA, Italy	Radionuclides as ocean tracers of physical processes
Pere Masqué	M	UAB, Spain	Environmental radioactivity and nuclear physics, GEOTRACES
Paul Morris	M	IAEA, Monaco	Radium and thorium isotopes and radionuclide databases
Deborah Oughton	F	NMBU, Norway	Radioecology and radioecological risk assessments
John Smith	M	BIO, Canada	Radionuclides in Arctic and other basins

* = co-chairs

Associate Members

Andy Johnson	M	Black Hills State Univ., USA	Teaching radiation literacy
Reiner Schlitzer	M	AWI, Germany	Data management and visualization, GEOTRACES database lead
Gary Hancock	M	CSIRO Australia	Soil erosion and sediment transport
José Godoy	M	PUC, Rio de Janeiro, Brazil	Ra, Po, Pb isotopes and groundwater discharge
Nuria Casacuberta	F	ETH, Switzerland	Sr, U and other radionuclide tracers
Jordi Vives i Batlle	M	SKC-CEN, Belgium	Radioecology and radiological protection
Vladimer Maderich	M	Inst. of MMSP, Ukraine	Radioactivity dispersion and fate models
Sandor Muslow	M	ICML, U. Austral de Chile	Radiotracers, stable isotopes and benthic ecology

Working Group contributions

While all Members will participate in all activities of the group, a short description of each full WG Member's unique professional activities and interests, as well as contribution to the WG is provided below.

Ken Buesseler specializes in the study of natural and artificial radionuclides in the ocean and their application to better understanding ocean processes. He will serve as co-Chair of the WG. He leads the Center for Marine and Environmental Radioactivity, the goals of which include increasing scientific and public understanding of radioactive substances in the environment, and training the next generation of marine nuclear radiation experts - all are key components of the RiO5 mission. Buesseler chaired SCOR WG 116 on Sediment Trap and ^{234}Th Methods for Carbon Export Flux Determination.

Minhan Dai uses a suite of radionuclides to examine carbon and trace metal biogeochemistry in marginal seas and estuarine systems, and investigates the geochemistry of radioactive elements in surface and ground water. He will serve as WG co-Chair and contribute by promoting links to research and radioecology in China and in Southeast Asia and will host a WG meeting at Xiamen University.

Michio Aoyama works on the geochemistry of ^{137}Cs in the world ocean from global fallout, and nuclear power plant accidents and has developed a marine radioactivity database, HAM, for artificial radioactivity in the world ocean. He will contribute by further developing and linking current databases of artificial radionuclides in marine systems.

Claudia Benitez-Nelson is an expert in the development of new radiochemical techniques and in the application of short-lived naturally and artificially occurring radionuclides in Marine Systems. A gifted teacher and mentor who has received numerous accolades for her ability to communicate her science to the broader community, she will contribute by coordinating the writing of the overview manuscripts and in the development of classroom and broader public education and outreach materials.

Sabine Charmasson's field of expertise is mainly radioecology with use of both natural and artificial radionuclides as tracers of transfer processes within ecosystems (primarily land-to-sea fluxes, sediment recording, food chain transfer). She will contribute by promoting links with EC research and radioecology, in the development of education and training tools, and with public dissemination.

Roberta Delfanti's research uses radionuclides as tracers of marine processes, including water dynamics in the Mediterranean Sea, and sedimentation and bioturbation in coastal and deep-sea environments. She will contribute by promoting links with eastern European research and radioecology, as well as education, training and public dissemination.

Pere Masqué's research focuses on using both natural and artificial radionuclides as tracers of processes in the ocean at various time scales, from present to paleooceanographic. A former member of the scientific steering committee of GEOTRACES, he will contribute by coordinating database efforts and in the development of education and outreach materials.

Paul Morris has worked with natural radionuclides to study ocean processes such as particle export and mixing rates. Currently, Morris works for the IAEA as the manager and coordinator of the Agency's Marine Information System (MARiS), and will contribute by further developing and linking current MARiS to other emerging data bases on artificial and natural radionuclides in marine systems.

Deborah Oughton's research includes the use of radioactive isotopes as environmental tracers as well as socio-ethical aspects of radiation risk assessment and stakeholder engagement. She will contribute by promoting links with EC research and radioecology, as well as education, training and public dissemination.

John N. Smith carries out targeted research focusing on applications of radioactive tracers to studies of sedimentation and particle transport, fish growth and other biological processes, biogeochemical cycling, ocean circulation and climate change. He will contribute by promoting links with North American research and radioecology, as well as education, training and public dissemination.

Relationship to other international programs and SCOR Working groups

We outline briefly below, some of the agencies and groups we have already spoken to, who will have a role to play in our WG activities. It is important to note that none of these organizations or groups have programs that would replace the need for RiO5, but they all can assist in those efforts in some way.

International Atomic Energy Agency (IAEA) and its Environment Laboratories in Monaco

One of the IAEA's mandates is to advise and assist Member States in building capacity for measurement and assessment of radionuclides in the marine environment and tracer applications to oceanographic, climate-related and pollution studies. Through its Marine Laboratories in Monaco (http://www.iaea.org/monaco/page.php?page=10) the IAEA is the world's major producer of reference materials of marine origin, and organizer of interlaboratory comparisons and proficiency tests. The IAEA maintains the MARiS database, containing over 120,000 records on radionuclides in seawater, marine sediment, and biota. Also, the WG co-Chairs are in discussions regarding an International Symposium with the IAEA, which, pending funding and approval, may be in a position to collaborate through dedicated sessions at a larger conference on nuclear applications in the marine environment.

European Nuclear Safety Training and Tutoring Institute (ENSTTI)

ENSTTI (http://www.enstti.eu/) was founded in 2011 and offers applied training course and tutoring sessions in nuclear safety, nuclear security and human and environmental radiation protection. On this latter point links could be developed with RiO5 in order to provide ENSTTI with baseline studies worldwide, to underline various processes that may enhance radionuclide transfer in the marine environment, even to contribute to ENSTTI training course on marine radioactivity and radioecology.

Center for Marine and Environmental Radioactivity (CMER)

CMER (http://www.whoi.edu/cmer) was established in early 2013 at the Woods Hole Oceanographic Institution with the goals of increasing scientific and public understanding of the sources, fate, and consequences of radioactive substances in the environment, and training the next generation of marine nuclear radiation experts. CMER will host this SCOR WG web site at WHOI, and assist in making links to public, student and academic audiences, building upon several efforts to pass on lessons learned from Fukushima, such as the *Oceanus* (http://www.whoi.edu/page.do?pid=83397&tid=3622&cid=175809) Japanese/English issue- *Fukushima and the ocean*- as well as a highly visited FAQ site (http://www.whoi.edu/page.do?pid=83397&tid=3622&cid=94989) on Fukushima ocean impacts. Also CMER can help organize and co-sponsor one of the WG meetings at WHOI.

Center for Environmental Radioactivity (CRAD)

CERAD (http://www.umb.no/cerad) is a Norwegian funded center of excellence hosted by the Norwegian University of Life Sciences and covering research and education on the sources, transfer, effects and risk assessment of radionuclides in the environment. In addition to fundamental research they are also engaged in stakeholder engagement and policy public issues. They are members of the Radioecology Alliance, and EC projects STAR, COMET, NERIS, DoReMi and OPERRA. They will contribute to training and education activities and links with EU radioecology and radiation protection

International Union of Radioecology (IUR)

The IUR (http://www.iur-uir.org/en) is an independent, non-political and non-profit scientific organization. Its first overarching role is to perpetuate a "think tank" capacity on radioecology issues through the maintenance of a network of scientists and professionals from around the world to foster communication between researchers from different fields and geographical regions through brain storming in task groups, the publication and circulation of technical papers, organization of conferences, training courses, and job alerts. At present there is no marine radioactivity task group, and this is something that RIO5 would be able to promote within IUR, and would be to the benefit of both organizations.

GEOTRACES

GEOTRACES (http://www.geotraces.org/) is an international and SCOR supported effort to map global distributions of selected trace elements and isotopes of key interest in ocean sciences. Two WG Members (Dai and Masque) are former members of the international GEOTRACES SSC, and Associate Member Schlitzer, is leading database efforts that we hope to incorporate into our WG to produce added-value to the efforts underway as part of this program.

Other collaborations

In addition to these groups, we will build relationships through our Full and Associate Members with a wider range of organizations, programs and working groups. Included among these are the Intergovernmental Oceanographic Commission (IOC-UNESCO) (http://ioc-unesco.org/) and the European ALLIANCE (http://www.er-alliance.org/) network and associated COMET and STAR consortiums. These groups will help to identify appropriate ways to ensure and facilitate the accomplishment of RiO5 objectives, including the training of new researchers in the field. European RiO5 WG Members will be proactive in raising funds for training thorough adequate platforms and instruments such as EU-funded Marie Curie Training Networks and/or COST-Actions (European Cooperation in Science and Technology), on which they already have experience.

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Appendix- five key publications from each full WG Member

Ken Buesseler

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