2. TC-IR Roadmap

Anthropogenic and Natural Radionuclides in Environment and Industry (Lena Johansson, NPL and Bruno Chauvenet, LNHB)

Drivers and challenges

a. Radioactivity in industrial processes

- Enhanced natural radioactivity (oil and gas, mining, sludge and waste material, raw and building materials, radon, …)

Naturally occurring radionuclides are present in many natural resources. Industrial activities that exploit these resources may lead to enhanced potential for exposure to Naturally Occurring Radioactive Materials (NORM) in products, by-products, residues and wastes. Uncontrolled levels of radioactivity associated with NORM can pose an objectionable economic burden for industry. The presence of NORM can lead to radiation doses that are not insignificant from a radiation protection point of view. Occupational exposure from natural source of radiation is estimated to contribute to more than 80% of the worldwide collective dose from occupational exposure, uranium mining excluded. Legislation is looking at protecting the public and radiation workers from ionising radiation by optimised application of industrial processes and non-destructive monitoring techniques.

- Release of radioactivity from medical and industrial production

Radioisotopes have long been fundamental tools used in science, medicine, and industry. Recent advancements in radiopharmaceuticals have revolutionized the diagnosis and treatment of cancer, heart disease, and other medical conditions, and, as a result, there is an increased worldwide demand for these radioisotopes together with a demand for reliable production routes by a variety of production methods.
Concurrent with the advances in medical and industrial isotopes, the scientific community has achieved breakthroughs in the detection of specific radioisotopes for national security purposes, e.g., the verification of compliance with nuclear treaties.
Unfortunately, similar isotopic signatures are often measured in effluents released by some of the medical isotope production facilities as in samples measured by the treaty monitoring community, although at levels well below those of naturally occurring isotopes (e.g., Rn-222 and its decay products). Furthermore, these effluents are frequently detected by advanced measurement network systems and can be a cause of ambiguity as to the source.
Recognizing the importance of both isotope production and nuclear treaty monitoring, it becomes necessary to better understand the challenges that production effluent signatures present in monitoring for treaty compliance and national safety and to propose ways to mitigate ambiguities as the production of isotopes increases to meet demand.

b. Nuclear Industry

After several decades of development and exploitation, but particularly after the Chernobyl and the Fukushima accidents, nuclear industry has to meet many challenges both for making it acceptable to the public and for enforcing its safety and sustainability.

Many nuclear facilities are coming to the end of their life. In the next decades, there will be an increasing number of decommissioning operations on contaminated sites and nuclear sites.

Nuclear waste disposal facilities are expensive and limited and there is a strict legal control of discharges of radioactivity from nuclear sites. Decisions will have to be made in several countries for the long-term management and storage of their nuclear wastes in dedicated sites. In some countries the low-level waste repositories are already reaching their limit.

New generation power plants will be developed and built (generation IV for fission, ITER for fusion).

New processes like spallation sources and transmutation of long-lived isotopes will be studied and developed (e.g. prototype of accelerator-driven reactor for transmutation “Guinevere” being installed at Mol, Belgium). Metrology across many science areas is required for successful completion of these goals and IR metrology is one crucial part.

c. Homeland security - Emergency preparedness

Illicit trafficking of explosives and nuclear material and detonation of radiation dispersion devices or improvised nuclear devices are major security challenges to EU citizens and economy. In addition, the fall-out of accidents of nuclear origin can also have major social and economic impact. More generally, the emergency preparedness and risk assessment capability in relation to any intentional or accidental nuclear event have become a major concern in each country. Ionising radiation techniques plays a key role in the prevention and reduction of significant security threats, national emergencies and improved personal safety.

d. Climate change

Climate change is one of the major concerns of today’s politics, economy, technology and research. Investigations have to be carried out to get a better and more accurate understanding of the different parameters impacting climate changes, either past, present or future and then get better models. In this respect, radionuclides play a significant role as tracers, mostly as isotopic ratios, of geochemical and /or biological phenomena, which can provide timescales for past climate changes. Measuring and modelling water flow in the oceans and atmospheric transport models on a global scale by radionuclide tracer applications will contribute to the understanding of possible climate change scenarios. Radionuclide dating techniques are useful tools in the investigation of ice cores where Pb-210/Po-210 are examples of radionuclides that can yield important information. Fossil CO_2 emissions can be monitored by C-14 measurements. The same technique can be applied to distinguish between the use of fossil or biofuel which benefit the European guidelines where CO_2 emissions from fossil fuel must be paid for to an increasing extent.

e. Science and Units

The quantity “activity” is related to the number of atoms via the radioactive half-life. Therefore there is a link between activity and the basic quantities of the SI “mole” or “mass”. This link could be explored using single-atom counting techniques.

A possible future science area would be the characterisation and development of dedicated industrial detectors e.g. pixel detectors for X-ray detection in space applications.

Targets

a. Radioactivity in Industrial processes
- Consistent and reliable control of naturally occurring radioactive materials. Conformity with ICRP latest recommendations and EU council directives (96/29/Euratom).
- Improve so far weakly developed end-user measuring systems and methods, in particular for in-situ use, and provide reliable instrumentation for monitoring and raw-material selection
- Support innovative processing technologies for the re-use of TENORM by-products and waste
- Support the cost-effective implementation of the EU Basic Safety Standards Revision concerning the NORM industry, building material industry and waterworks
- Support the global competitiveness of the European NORM/TENORM industry
- Eliminate technical trade barriers and prevent trade disputes between EU member states
- Support the economically effective implementation of the emerging revised European Directive on radioactivity in drinking water

b. Nuclear industry
- Better acceptance of nuclear industry by new metrology for improved safety, sustainability and reduced environmental burden.
- Better and safer control of decommissioning operations and improved accuracy in waste sentencing.
- Reduced environmental impact and socio-economic benefits from better control of radioactive waste. Metrology would include transmutation techniques for radionuclides belonging to high-level long-lived wastes.
- In-situ cost-effective and safe analysis techniques to support radioactive waste management and low-level radioactivity analysis techniques.

c. Homeland security
- More reliable and more sensitive diagnosis of crisis situations after radiation dispersion due to intentional or accidental nuclear events.
- Stand-off detection of radioactive materials, i.e. utilizing scintillations (UV), heat, ions or radiolysis products.
- Development of cross disciplinary techniques, e.g. combining optics and conventional nuclear physics etc.
- Early detection with no false positives of illicit presence of radioactive material.
- Develop methods for nuclear forensics – i.e. use radionuclide ratios to specify type and location of event.
- Efficient monitoring of environment and food-stuff in case of event occurred.
- Effective large- and small-scale de-contamination methods applied to affected areas or specimen. Development of quick, specific, high-yield chemical analyses that may rely on microfluidic techniques.
- Metrology for decision making of food intake.

- Estimation of dose to human and biota for prediction of long-term effects from ionising radiation and input to epidemiology.

d. Climate change
   - Public understanding of the reality of anthropic climate change and tools for decision making for politicians.
   - Improved validated models for climate change by development of oceanographic and atmospheric monitoring while employing existing monitoring networks and satellite data.
   - Estimated effects of climate change by radiotracers in the oceans and polar ice mass with low-level techniques including possibilities such as accelerator based mass spectrometry and in the atmosphere by direct or indirect radon measurements.
   - Support the development of radionuclide dating techniques in order to understand long-term changes in climate.

e. Science and Units
   - Establish a link between the Becquerel and the SI unit for mole (or mass)
   - Apply developed technology and methodologies to other important area of science

Deliverables

a. Radioactivity in industrial processes
   - Development of reference materials and dedicated radioactive standards for radioactive gases, liquids and solids
   - Design traceable and metrological sound measurement procedures (as input to e.g. CEN/ CENELEC standards) for industrial NORM raw material, products, by-products, residues, and waste
   - Development of measurement systems, methods and techniques including in-situ systems which support innovative industrial processing of resources containing naturally occurring radioactive material
   - Mathematical and stochastic modelling of industrial systems
   - Detector simulation for determination of efficiency and corrections
   - Testing of developed systems, standards and reference materials in industrial processing situations
   - Development of Statistical analysis of minimum detectable activity in samples with impurities
   - Improvement of decay data of radionuclides used for medical and industrial purposes or as nuclear explosion signatures (e.g. ^{127}Xe, ^{133m}Xe, ^{133}Xe, ^{135m}Xe, ^{135}Xe)

b. Nuclear Industry
   - Development of reference materials, including some characterized both in terms of activity and chemical speciation.for waste sentencing and follow-up testing by commercial detectors such as gamma-scanners. Improvement of 3D imaging of waste containers.
   - Development of standards and 'spiked' or characterized 'real' reference materials for ensuring accurate, traceable radio-assays of materials from sites (concrete, steel, aluminium etc.).
   - Development of traceable monitoring instruments for on-site, real-time measurements of radioactive aerosols and gases in nuclear facilities.
   - Development of novel instruments and methods for in-situ measurements: improved on-

site radiochemical analysis, rapid in-situ screening techniques for alpha, beta and gamma emitters, measurement of activity at varying depth.

- Tests of developed radionuclide metrology using coincidence counting techniques and digital electronics in nuclear power plant test-facility. Improved neutron cross-sections for fast neutrons and testing of related transfer instrumentation for neutron fluence measurements.
- Improved nuclear decay data for operation of Gen IV and fusion reactors. Determination of neutron-induced independent fission yields as a function of neutron energy and target. These yields are important for the design of gas cooled GenIV fast reactors.
- Detector development and mathematical and stochastic modelling for improved radionuclide depth profiling in matter.

c. Homeland Security

- New and improved detectors for European monitoring networks and development of suitable and traceable calibration standards for relevant radionuclides in gaseous, liquid and solid form. Improved methods for radionuclide ratio speciation by combined metrology techniques including bolometry, mass spectrometry and radiometry.
- Investigate feasibility of techniques for large-scale decontamination by chemical or biological methods or nano-particles tailored to specific radionuclide.
- Validation of contamination detectors applied for sentencing of food-stuff.
- Reference materials and surface contamination standards
- On-site transportable measuring instruments
- Development of traceable 2D measurements (gamma-cameras) for localisation and evaluation of contaminated surfaces.
- Improvement of decay data of radionuclides important in nuclear treaty monitoring (e.g. ^{131m}Xe, ^{133m}Xe, ^{133}Xe, ^{135}Xe). Determination of neutron-induced independent fission yields as a function of neutron energy and target.

d. Climate change

- Improved standards and decay data for radionuclides of interest for tracer measurements (e.g.^{99}Tc, ^{36}Cl, ^{129}I, ^{220}Rn) and dating (e.g.^{14}C, ^{210}Pb/Po).
- Standardisation of cosmogenic radionuclides (e.g. ^{10}Be, ^{26}Al, ^{36}Cl)
- Development of highly sensitive mass spectrometry – either accelerator mass spectrometry or resonance ion mass spectrometry – that can be housed in conventional laboratory space
- Using ion trapping and ion fountain techniques to measure $<10^5$ atoms/sample
- Ruggedising microcalorimeters to allow field and routine laboratory measurements to be made.
- Employ European Ionising Radiation Early Warning networks, operated on national basis in many countries to harmonised across country borders
- Investigate if a traceable link between outdoor radon-activity-concentration in air and soil moisture can be established. Radon is used as a passive tracer in atmospheric research to examine transport processes. Soil moisture data is since 2009 captured by the ESA satellite SMOS.

Technologies

- Digital instrumentation and dedicated signal processing software
- Pixel detectors and array detectors
- Measurement networks
- Coincidence counting techniques
- Improved basic metrology instrumentation and methods (liquid scintillation, gas counters,…)
- Improved tools for spectrometry techniques:
  - x-ray spectrometers with extended energy ranges
  - beta spectrometers with low energy threshold and high energy resolution
  - reference x-ray beams in the low-energy range (some hundreds of eV up to 30 keV)

Enabling Science

- Nuclear Physics - Decay schemes
- Digital Signal processing
- Monte-Carlo simulation radiation-matter interactions
- Detector modelling
- Development of techniques for Primary standards
- Radiochemical analysis
- Mass spectrometry

Stakeholders

- SNETP – Sustainable Nuclear Energy Technology Platform,
- MELODI – Multidisciplinary European Low-Dose initiative,
- European Radioecology Alliance,
- NERIS-TP – Technology platform for nuclear and radiological emergencies,
- EURADOS – European Dosimetry Group,
- ESARDA - European Safeguards Research and Development Association,
- IGD-TP – Implementing Geological Disposal of Radioactive Waste – Technology Platform,
- Euratom