Eur. Phys. J. Plus (2025) 140:1003
https://doi.org/10.1140/epjp/s13360-025-06898-6

THE EUROPEAN PHYSICAL JOURNAL PLUS

Regular Article

Strategic research agenda and roadmaps for radiation protection metrology

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Received: 27 June 2025 / Accepted: 23 September 2025

Abstract EURAMET EMPIR 19NET03 *supportBSS* project entitled *Support for a European Metrology Network (EMN) on reliable radiation protection regulation*, started in June 2020 and completed in May 2024. One of the tasks of the *supportBSS* project was the preparation of a Strategic Research Agenda (SRA) based on the identified metrology needs to support the European legislation and regulation in Radiation Protection, and of two Roadmaps for metrology services and capabilities, one under the European Council Directive 2013/59/EURATOM and the other under the EURATOM Treaty. The preparation of the SRA began with a comprehensive literature review including the analysis of the SRAs from the MEENAS Radiation Protection platforms and of strategic documents from other relevant organizations such as IAEA, BIPM-CCRI, HERCA, EURAMET, among others. Information was also collected from the stakeholders at different stages of the project, through organized workshops and a targeted questionnaire, which included specific sections for metrology laboratories and for stakeholders from the different fields of activity. This paper presents the first SRA and Roadmaps developed as key outputs of the *supportBSS* project, presented to EURAMET as deliverables 4 and 5 at the closure of the project. Taking into account the ongoing technological developments in the field, as well as the fact that EURAMET may use the information collected at its own discretion, it is anticipated the European Metrology Network for Radiation Protection will need to periodically revise and update these documents in the near future.

1 Introduction

The European Association of National Metrology Institutes (EURAMET) through its European Metrology Programme for Innovation and Research (EMPIR) funded the project entitled *Support for a European Metrology Network on reliable radiation protection regulation* (EMPIR 19NET03 *supportBSS*), active from June 2020 until May 2024.

The project aimed to establish a European Metrology Network (EMN) for Radiation Protection (RP), EMN-RP. It was structured into seven work packages (WPs), namely: WP1—Implementing a long-term ongoing dialogue between the metrology community and the relevant stakeholders; WP2—Preparation of web portal for radiation protection regulation; WP3—Development of a Strategic Research Agenda (SRA) and Roadmaps; WP4—Knowledge-sharing and capacity building in Europe; WP5—Joint and sustainable European metrology infrastructure; WP6—Creating impact, and finally, WP7—Management and Coordination. More information about the project and its outcomes can be found in www.euramet.org.

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Published online: 18 October 2025

Table 1 Acronyms of the organizations mentioned in the text

MEENAS	The consortium of the European Radiation Research Platforms MELODI, EURADOS, EURAMED, NERIS, ALLIANCE and SHARE
MELODI	Multidisciplinary European Low Dose Initiative
EURADOS	European Radiation Dosimetry Group
EURAMED	European Alliance for Medical Radiation Protection Research
NERIS	European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery
ALLIANCE	European Radioecology Alliance
SHARE	Social Sciences and Humanities research related to Ionising Radiation
IAEA	International Atomic Energy Agency
BIPM-CCRI	Bureau International des Poids et Mesures, Consultative Committee for Ionising Radiation
HERCA	Heads of Regulatory Competent Authorities
EURAMET	European Association of National Metrology Institutes
CONCERT	European Joint Program for the integration of Radiation Protection Research
SAMIRA	Strategic Agenda for Medical Ionising Radiation Applications

The EMN-RP was officially established in September 2021 to serve as a central platform for collaboration between the metrology community and stakeholders involved in ionising radiation (IR) regulation. Its purpose is to ensure quality assurance for measurements in all exposure situations contemplated in the European Legislation [1–4]. Table 1 in reference [4] summarizes several key documents issued by the European Commission and the European Atomic Energy Community that outline metrology support needs.

The mission of EMN-RP is: *To support European legislation and operators with reliable data including uncertainties and to clearly express where such reliable data is not available. To jointly use national capacities to overcome the gaps in the data; To provide expertise for measurements and quality assurance in exposure situations addressed under the European legislation; To raise awareness about the shortcoming in radiation protection funding of the past and to change the steering process for the future*. Further information available at https://www.euramet.org/european-metrology-networks/radiation-protection.

Work package 3 (WP3) of the 19NET03 *supportBSS* project focussed on preparing a Strategic Research Agenda (SRA) based on the identification of metrological needs to support the European legislation and regulation in Radiation Protection, as well as two Roadmaps for metrology services and capabilities, one under the European Council Directive 2013/59/EURATOM [5] (hereafter, the BSS), and the other under the EURATOM Treaty [6]. The aim of this paper is to present the SRA and the accompanying roadmaps produced as key outputs of the *supportBSS* project to the community.

2 Preparation of the SRA

The collection of information necessary to the development of a SRA for the metrology services needed to underpin radiation protection regulation began with an extensive literature review. This review focussed on identifying existing research priorities and strategic objectives relevant to the field, based on the publications issued by the consortium of the European Radiation Research Platforms, such as: MELODI, EURADOS, EURAMED, NERIS, ALLIANCE and SHARE (all together forming MEENAS). The SRAs of the Radiation Protection platforms MELODI [7], EURADOS [8], EURAMED [9], NERIS [10], ALLIANCE [11] and SHARE [12], were studied and analysed, as well as equivalent documents recently published by relevant organizations to this field, such as, the IAEA [13], BIPM-CCRI [14], HERCA [15], EURAMET [16], EJP-CONCERT [17] and SAMIRA [18], among others. Table 1 lists the correspondence between the acronyms and designations of the above-mentioned organizations.

The analysis of the SRA and the equivalent strategic documents of relevance was performed looking for the topics recommended at the *supportBSS* Gaps Workshop, held in September 2020, and presented at the 9th International Conference on Radiation in Various Fields of Research (RAD 9) in 2021 [19]. The following topics were analysed: (i) Reference fields; (ii) Radiation protection quantities: improving the concepts of dose quantities; (iii) Education and training needs; (iv) Measurement devices for RP in medical or industrial applications of IR or for environmental monitoring, including handling and transmission of measurement data; (v) Activity standards; (vi) Type testing: harmonization and national requirements in RP legislation, ISO standards and accreditation. The study of the SRAs suggested the additional topics: (vii) Development of the metrological infrastructure; (viii) Metrology capability for nuclear and atomic data determination with significantly improved uncertainties; (ix) Understanding and quantifying the health effect of radiation exposure; (x) Understanding radiation-related effects on non-human biota and ecosystem; (xi) Characterization of exposure; (xii) Individual dosimetry: Improving radiation protection of workers; (xiii) Optimizing medical use of radiation: Quality metrics for diagnostic imaging and therapy; (xiv) Sources and influences of uncertainty.

An internal report [20] compiling the analysis of these topics, based on the reviewed SRAs and strategic documents was prepared (July 2021) but was considered difficult to read and to handle. A decision to simplify the subjects addressed by both the BSS and the EURATOM Treaty was taken at the project Workshop held at IST (Portugal) in April 2022. The subjects were grouped in four fields

of activity: "Public, environmental and Ionising Radiation in the ecosystem", "Emergency exposure", "Occupational exposure" as well as radiation protection topics in "Medical use of Ionising Radiation". Concerning the last field of activity, care was taken in order to avoid superposition with project EMPIR 19NET04 MIRA *Support for a European Metrology Network on the medical use of ionising radiation*, that was running at that time. Unfortunately, project MIRA produced no results and the corresponding EMN was not established. It is anticipated that more recently, in 2025, EURAMET determined the Technical Committee on Ionising Radiation (TC-IR), within its Working Group Health would be responsible for the issues related to "Radiation in Health".

In April 2023, a questionnaire [21] entitled *Metrology supporting the European regulation for radiation protection* was prepared with questions to all stakeholders, to metrology laboratories and specific questions for the fields of activity mentioned above. The aim of this questionnaire was to get the stakeholder feedback on the important topics for research on metrology to support the European regulation on radiation protection, their relevance and prioritization.

The questionnaire was accessible via a link to an electronic platform provided by STUK and the communication strategy established in WP1 used to send the link to all *supportBSS* stakeholders. Institutions and organizations addressed were representatives from academia, authorities, research institutes, hospitals and clinics, providers of measurement devices, metrology laboratories (National Metrology Institutes, Designated Institutes, Secondary Standard Dosimetry Laboratories), radiation protection platforms and service providers, specifically, ALLIANCE and EURADOS working groups on individual and environmental monitoring. In total, responses were received from 59 institutions or organizations from European countries, as well as from the Republic of South Africa, Kazakhstan and Uruguay.

A preliminary analysis of the replies to the Questionnaire was presented at the European Radiation Protection Week (ERPW) 2023 [22]. An extended version was prepared combining all the replies to the Questionnaire and previous work [20] into a first draft [23] of the SRA with fourteen identified topics for research organized into thirteen chapters and an additional one on Education and Training, that circulated among the project partners and stakeholders for comments and suggestions together with a request for prioritization. The draft was improved with a short justification for each of the 14 chapters (topics and subtopics) prior to the last stakeholder Workshop held at ASNR in Cadarache (France), in April 2024, where it was presented and discussed. It was again distributed to the partners as well as to the stakeholders, for further improvements.

The final version of the SRA presented to EURAMET is listed in the following section, reflects a broad consensus among the project partners and external stakeholders.

3 The SRA prepared by the *supportBSS* project

The Table of Contents of the SRA [24] presented to EURAMET as a deliverable of the *supportBSS* project is listed below. It contains the relevant topics for research in metrology organized in chapters each with several subtopics, and although a prioritization was made, the chapters are listed in arbitrary order. In line with the protocol of the *supportBSS* project, the topics were organized in terms of Technical Applications (Chapters 1–4, 8–10, 12 and 13), Environmental factors (Chapters 6, 7, 10 and 13), Safety (Chapters 5, 10 and 13), and a mix of all three (Chapters 10 and 13).

Some research topics might be of common interest to other EMNs of EURAMET such as for EMN for Mathematics and Statistics (EMN Mathmed), EMN for Pollution Monitoring (EMN PolMo), EMN for Climate and Ocean Observation (EMN COO) and EMN for Clean Energy, and these synergies are identified in the chapter titles.

The table of contents of the SRA is as follows:

1. New approaches in computational dosimetry (partially in collaboration with EMN Mathmet)
   - 1.1 Development of computational and AI-supported dosimetry as alternatives for dosimetry in some workplaces;
   - 1.2 Development and validation of more realistic reference calibration phantoms (physical and computational);
   - 1.3 Testing and approval criteria including uncertainty assessment for computational and AI-supported dosimetry;
   - 1.4 Increased speed and accuracy of computational and AI-supported dosimetry to improve the radiation protection of workers through better real-time visualization of radiation fields also with the inclusion of augmented reality;
   - 1.5 Computational and AI-supported dosimetry to improve shielding calculations.
2. New reference fields following technological developments
   - 2.1 Dosimetry in pulsed fields with active devices;
   - 2.2 Specific reference fields for pulsed fields (for example accelerators);
   - 2.3 Reference fields to replace radioactive sources like e.g. Cs-137, Co-60, Am-241, and Cf-252;
   - 2.4 Spectrometry of reference fields, simulation, determination of conversion coefficients and uncertainty estimation;
   - 2.5 Neutron reference fields (thermal fields, workplace fields);
   - 2.6 Reference fields for realistic exposure conditions to enable more accurate assessment and protection.
3. New approaches for operational quantities (like ICRU 95)
   - 3.1 New secondary standards;

3.2 New/modified dosemeters;
3.3 Development of instruments to measure photon and electron components separately;
3.4 Reference fields for the new ICRU95 quantities in non-charged particle equilibrium conditions;
3.5 Scattered radiation in typical workplace (<60 keV).

4. Radiation protection for a stronger Europe: cohesion

4.1 Handling of differences in metrology related regulations in the European Union member states (exposure assessment, type testing, calibration, verification, characteristic limits and uncertainty assessment), provision of a strategy for cohesion;
4.2 Harmonization of type test requirements in international standards covering similar measuring tasks (for example area and environmental dosimetry);
4.3 Harmonization of new technologies and methodologies for environmental monitoring;
4.4 Development of photon dosemeters for lower energies (from 12 keV for $H^*(10)$, from 5 keV for $H'(0.07)$, active $H'(3)$ area dosemeters, e.g. mammography, ultra-short-pulsed lasers);
4.5 Guidelines for the handling of large number of measurements (type testing of devices, citizen science and sensor networks).

5. New approaches in emergency preparedness, quick response and enhanced resilience

5.1 Metrological support for the early warning networks and EURDEP: reliability of sensor networks; type testing of devices; quality assurance; regulation for the handling of large volume of measurements.
5.2 Citizen science: development of reliable and cheap dosemeters for public use, especially in case of emergency. Development of quality assurance methodologies. Use of big data for emergency response to optimize RP of large numbers of citizens (estimation of risks and optimization of countermeasures);
5.3 Development of unmanned ground and aerial vehicles for monitoring;
5.4 Real-time measurements of external radiation and airborne and marine radioactivity, new sensors;
5.5 New equipment and methods for in vivo and in vitro monitoring of radionuclides incorporated in the body, especially for a large number of individuals.

6. Strengthening of environmental monitoring (partially in collaboration with EMN PolMo)

6.1 Implementation of radon measurements at environmental monitoring stations;
6.2 Radon/thoron metrology in sensor networks e.g. for big buildings and future cities;
6.3 Pollution monitoring of radioactive isotopes from waste or accidents;
6.4 Metrology for radioactive tracers in radiation protection and climate observation especially in between different compartments (e.g. soil-air, water-air);
6.5 Dosimetry for wildlife and species of reference;
6.6 Muon-dosimetry and related instrumentation development;
6.7 Dosimetry for solar particle events.

7. Supporting climate change observation instrumentation (partially in collaboration with EMN COO)

7.1 Crossover projects in the field of climate change making use of natural radioactivity or natural ionising radiation;
7.2 Providing new data for digital twin of planet earth;
7.3 Providing reliable data bases for radiation interaction with atmospheric constituents like greenhouse and other atmospheric relevant gases, aerosols and pollutants, investigation of cross-effects on UV and IR radiation);
7.4 Development and validation of novel methods for using radionuclides as tracers for climate relevant processes;
7.5 Improving quality and traceability of soil humidity measurements by radiation measurements (e.g. with neutrons).

8. Adaption of radiation protection of staff due to developments in medicine

8.1 Dosimetry of staff (whole-body, extremity and eye lens) in radiology and in interventional radiology;
8.2 Dosimetry of staff in nuclear medicine;
8.3 Dosimetry of staff in the case of accidents in medical workplaces;
8.4 Dosimetry to validate accelerator facility shielding, including FLASH radiotherapy facilities.

9. Adaption of activity standards to new needs

9.1 Lower limit values–activity standards for calibration at small order of magnitude;
9.2 Reference values–Certified reference materials;
9.3 New radionuclides for nuclear medicine (poorly known decay schemes, short half-life, complex chemistry and impurities).

10. New developments in energy production: nuclear power and waste-management related (partially in collaboration with EMN Clean Energy)

10.1 Recycling and reuse of radioactive material and naturally occurring radioactive materials (NORM);

10.2 Characterization of radioactive and nuclear waste (nuclide-specific activities);
10.3 Need for traceable measurements for NORM;
10.4 Develop methods to perform (nuclide specific) measurements for clearance of materials in decommissioning;
10.5 Neutron dosimetry;
10.6 Small Modular Reactors: releases and accidents; online monitoring;
10.7 Occupational and public exposure;
10.8 Radioactive pollutants in the environment;
10.9 Incorporated radionuclides;
10.10 Radiation protection issues for future fusion reactors.

11. New security situation: Nuclear Threat and Counter Terrorism

11.1 Safety and security issues for nuclear installations;
11.2 Detection and monitoring networks for nuclear detonations;
11.3 New X-ray screening methods in support of counter terrorism units, e.g. at airports, ports, etc.

12. Further important Topics of Interest

12.1 Muon-dosimetry and general radiation protection aspects at high power laser facilities, e.g. Extreme Light Infrastructure, ELI, (s. also CCRI strategy paper [25]);
12.2 Digitalization/big data (real time, online data for regulators; reliability, usability, uncertainties and interpretation of data combined from multiple sources; handling of big data: reliability, accuracy and uncertainties; quality assurance);
12.3 Dosimetry for space flights;
12.4 Cross-sectional data for high energies.

13. Education and training

13.1 Clarification of metrology terms (traceability, calibration, verification, type testing and uncertainty);
13.2 Relative importance of terms and related actions weighted with the field of work (medical field, industry, radiation protection, public e.g. citizen science);
13.3 Dosimetry and Emergency Preparedness;
13.4 (European) Regulation for measurement devices (Guidance on the implementation of regulations in metrology);
13.5 Drafting national regulations on metrology;
13.6 Better information sharing;
13.7 Services required by the legislation which laboratories are not able to perform;
13.8 Regulation for the handling of large volume of measurements (type testing of devices, citizen science and sensor networks).

14. Topics related to developments in fields in medicine (in parts in collaboration with a future EMN for medical applications)

14.1 Reliability of dose data provided by built-in measuring and computational devices in X-ray units (mammography, conventional, CT and angiography);
14.2. The utility and traceability of calibration radiation qualities primarily used for instruments in the medical field (reference fields versus clinical fields);
14.3. Dosimetry for proton and ion beam radiotherapy;
14.4. Accuracy of radionuclide activity measurements with radionuclide calibrators;
14.5. Traceability for brachytherapy;
14.6. Measurements of ionising radiation in intense magnetic fields (Magnetic Resonance imaging (MRI)-guided radiotherapy);
14.7. New radionuclides for diagnostics, therapy or theranostics;
14.8. Neutron reference fields (thermal fields, workplace fields, epithermal region for e.g. Boron neutron capture therapy (BNCT)).

4 Preparation of two Roadmaps

Another task of WP3 within the *supportBSS project* was the development of two Roadmaps addressing the metrology needs for Radiation Protection. One is based on the European Council Directive 2013/59/EURATOM [5] and another on the EURATOM Treaty [6], Roadmaps 1 and 2, respectively. The roadmaps outline a strategic framework that includes Triggers, Topics to inspire or motivate science and technology, Metrological Applications required to achieve defined Targets, in a timeframe covering the next 10 years, from 2025 to 2035.

Roadmap 1 was developed based on the SRA and structured along the same three thematic pillars: (i) safety, (ii) technical applications and (iii) environmental factors, as mentioned above.

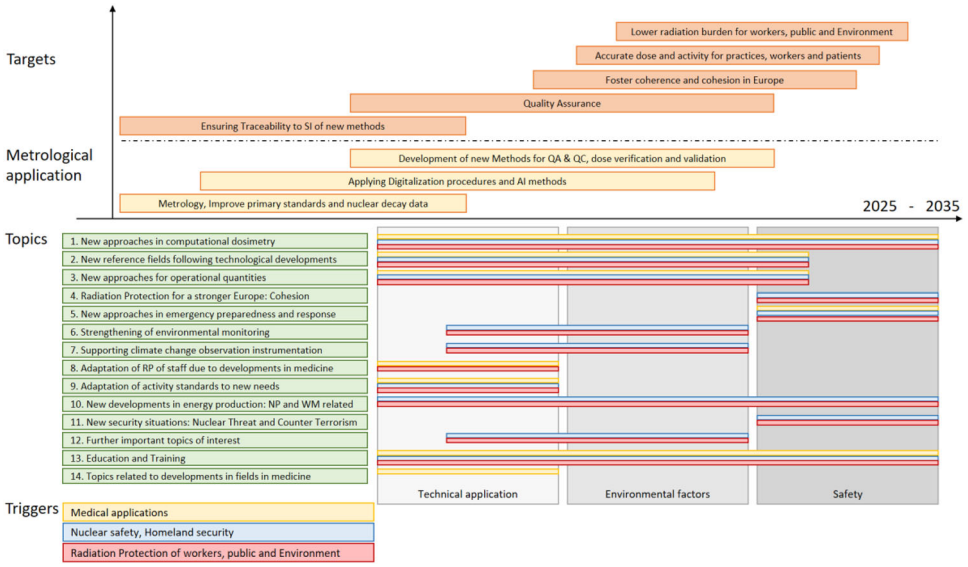

Fig. 1 Roadmap 1: BSS Council Directive—SRA

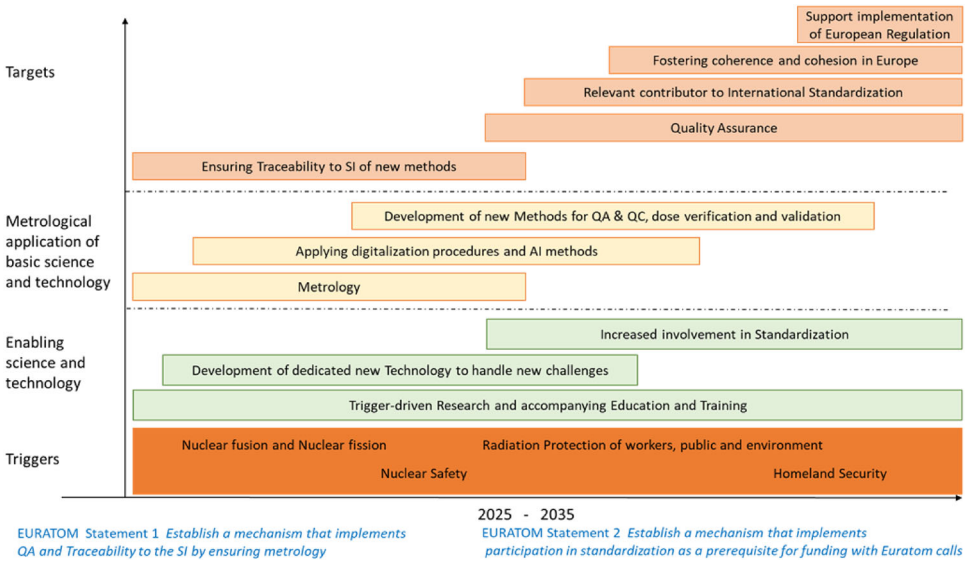

Fig. 2 Roadmap 2: EURATOM Treaty Statements 1 and 2

Roadmap 2, on the other hand, was developed based on the key objectives of EURATOM Statements 1 and 2, respectively, *Establish a mechanism that implements QA and Traceability to the SI by ensuring metrology* and *Establish a mechanism that implements the participation in standardization as a prerequisite for funding with Euratom calls*.

Draft versions of both Roadmaps were sent to the partners and stakeholders prior to the workshop held at ASNR in Cadarache (France), in April 2024. During the workshop, the drafts were presented, discussed and improvements were requested. The Roadmaps 1 and 2 presented to EURAMET as a deliverable of the *supportBSS* project are shown in Figs. 1 and 2, respectively.

5 Conclusion

The aim of this paper was to present to the Radiation Protection community several key outputs [26] of the EMPIR 19NET03 *supportBSS* project:

- Strategic Research Agenda for metrology services underpinning radiation protection regulation: 14 chapters were organized in terms of Technical Applications, Environmental factors and Safety;
- Roadmap 1 prepared for the Council Directive 2013/59/EURATOM (BSS);
- Roadmap 2 prepared for EURATOM Treaty Statements 1 and 2;

Throughout the course of the project, from 2020 until 2024, the stakeholders were engaged in the activity of the project and their contribution was requested by attending workshops, replying to questionnaire, defining prioritizations, at various stages. As a result

of this sustainable engagement, it is reasonable to conclude that both the SRA and the Roadmaps reflect a broad consensus among the stakeholders involved.

These documents represent the first SRA and first Roadmaps produced by the *supportBSS* team and presented to EURAMET at the end of the project. Taking into account the ongoing technological developments in the different fields, it is anticipated that regular updates of the SRA and Roadmaps will be necessary. On the other hand, in the future EURAMET may determine that specific issues are dealt with by other EMNs or Technical Committees, e.g. Chapters 9 and 14 falling under the responsibility of WG Health of TC-IR.

To this end, the EMN-RP has already established a dedicated task group responsible for monitoring developments and coordinating future updates to the SRA.

Funding This work was prepared in the framework of project EMPIR 19NET03 supportBSS work package 3 on the development of a Strategic Research Agenda (SRA) and Roadmaps for metrology services underpinning radiation protection regulation. 19NET03 supportBSS has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme. 19NET03 supportBSS denotes the EMPIR project reference.

Data Availability Statement Data that support the analysis presented in the manuscript are listed in the references and accessible with links to the respective organization web page or using a persistent identifier, such as the corresponding DOI, when available. References [20] and [23] are internal reports produced by the project team and may be available upon request. The manuscript has associated data in a data repository.

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