

NUCLEAR-POWERED VESSELS AND ENVIRONMENTAL RISKS: CLOSING THE REGIONAL NUCLEAR EMERGENCY PREPAREDNESS GAP

Julius Cesar Trajano

The growing presence of nuclear-powered submarines in the Asia-Pacific introduces environmental and maritime security risks that warrant greater regional attention. Although these vessels have generally strong safety records, accidents cannot be entirely ruled out. At least nine nuclear-powered submarines have sunk in the world's oceans, leaving reactors, spent nuclear fuel, and other radioactive materials on the seabed. Over time, radioactive materials can leak into the surrounding marine environment, potentially affecting marine ecosystems, fisheries, and human health and livelihoods.

One notable example is the Soviet nuclear-powered submarine K-278 *Komsomolets*, which sank in the Norwegian Sea in 1989 following an onboard fire. A joint Norwegian–Russian expedition in 2019 detected radiation levels near the wreck that were hundreds of thousands of times higher than normal background levels.¹ Such incidents demonstrate that the environmental consequences of nuclear-powered submarine accidents can persist long after the initial event, with potential implications for fisheries, migratory fish stocks and marine ecosystems.

The Asia-Pacific has not been immune to accidents involving nuclear-powered submarines. In 1985, the K-431 Soviet submarine suffered a reactor accident during refuelling at Chazhma Bay near Vladivostok, resulting in radioactive contamination.² More recently, in 2017, India's INS *Arihant* reportedly experienced flooding in its reactor compartment, demonstrating how human error and operational mishaps can threaten nuclear-powered submarine systems even without a reported radiological release.³ These cases underscore that the risks associated with nuclear-powered submarines extend beyond reactor safety to include navigation, maintenance, human error and operational procedures.

The USS *Connecticut* (SSN-22) incident in October 2021 provides a particularly relevant example for Southeast Asia. The US Navy's nuclear-powered attack submarine struck an uncharted underwater seamount while submerged in the South China Sea during a high-speed transit. Although its nuclear propulsion plant was not damaged and no radioactive material was released, the collision injured 11 crew members and caused significant damage to the vessel, requiring

¹ Michelle Starr, "Sunken Soviet Submarine Is Leaking Radioactive Material in the Ocean," *ScienceAlert*, March 24, 2026, <https://www.sciencealert.com/sunken-soviet-submarine-is-leaking-radioactive-material-in-the-ocean>.

² International Atomic Energy Agency, *Lessons Learned from the Response to Radiation Emergencies (1945–2010)* (International Atomic Energy Agency, 2012).

³ Zia Mian et al., "Nuclear Submarines in South Asia: New Risks and Dangers," *Journal for Peace and Nuclear Disarmament* 2, no. 1 (2019): 184–202, <https://doi.org/10.1080/25751654.2019.1621425>.

extensive repairs. The incident demonstrated that even highly capable nuclear-powered submarines can be exposed to navigational and operational risks in Southeast Asian waters.⁴

Southeast Asia has not yet experienced a major nuclear or radiological accident involving a nuclear-powered submarine. Nevertheless, the increasing deployment and transit of such vessels through regional waters mean that the possibility of a maritime accident, however unlikely, warrants greater consideration. This is particularly important for a region heavily dependent on the marine environment for fisheries, food security, trade and livelihoods. A radiological incident at sea could generate environmental, economic and humanitarian consequences that extend beyond national jurisdictions. As naval activity intensifies, ASEAN states therefore need to consider the environmental and transboundary implications of nuclear-powered submarine accidents as part of broader discussions on nuclear safety, risk reduction, and emergency preparedness and response.

This paper argues that Southeast Asia's nuclear governance architecture should evolve beyond its predominantly national and land-based focus towards a more integrated regional approach to transboundary nuclear and radiological emergencies at sea. ASEAN already possesses important foundations for such cooperation through the ASEAN Network of Regulatory Bodies on Atomic Energy (ASEANTOM), the ASEAN Protocol for Preparedness and Response to a Nuclear or Radiological Emergency, regional radiation-monitoring initiatives and emergency exercises. The paper first examines the environmental risks associated with nuclear-powered submarine accidents, before considering their potential impacts on fisheries and food security, particularly in the interconnected waters of the South China Sea. It then assesses pathways for strengthening nuclear emergency preparedness through ASEANTOM and wider regional cooperation, followed by an examination of national initiatives and the remaining gaps in maritime preparedness. The paper concludes with policy recommendations for strengthening ASEAN's capacity to anticipate, monitor and respond to potential maritime nuclear and radiological emergencies.

The transboundary risks of maritime nuclear accidents

A shared sea, a transboundary risk

Although Southeast Asian waters have so far avoided a serious accident involving a nuclear-powered submarine, the following analyses illustrate why the growing presence of such vessels in the region warrants greater attention to accident prevention, environmental monitoring and emergency preparedness.

The South China Sea is characterised by complex monsoon-driven circulation. Radioactive materials released from an accident would not remain confined to one location but could be transported across national maritime boundaries. Recent ocean modelling demonstrates that dissolved radionuclides such as tritium can spread across much of the South China Sea within a

⁴ Sam LaGrone, "Investigation: USS Connecticut South China Sea Grounding Result of Lax Oversight, Poor Planning," *USNI News*, May 24, 2022, <https://news.usni.org/2022/05/24/investigation-uss-connecticut-south-china-sea-grounding-result-of-lax-oversight-poor-planning>.

few months, with transport patterns varying seasonally.⁵ Because the South China Sea is a semi-enclosed sea shared by multiple coastal states, contamination could become a regional rather than purely national issue. Countries such as Vietnam, the Philippines, Malaysia, Brunei, Indonesia, and China could all be affected depending on prevailing currents and the accident location. This would require coordinated environmental monitoring, information sharing, and emergency response.

If the submarine's reactor compartment or spent nuclear fuel were damaged, radionuclides could be released into surrounding seawater. Initially, contamination would be concentrated near the accident site before dispersing through ocean currents. Depending on the radionuclides involved, contamination could persist for years or decades.⁶

Fisheries and food security on the frontline

The South China Sea is not only a strategically important waterway but also a critical source of food, livelihoods and economic activity for coastal communities across Southeast Asia. This makes the potential environmental consequences of an accident involving a nuclear-powered submarine particularly significant. Even where radioactive contamination is limited in geographic extent, uncertainty about the presence and movement of radioactive materials could have consequences far beyond the immediate accident site.

Temporary fishing closures may be imposed as a precautionary measure, while seafood products from affected areas could face additional monitoring, import restrictions or consumer avoidance. For fishing-dependent communities, the resulting loss of income could persist even after environmental monitoring determines that contamination levels have returned to safe levels. The disruption could also affect processors, traders, restaurants and exporters throughout interconnected regional seafood supply chains.

This risk is particularly important in the South China Sea because marine environmental problems are inherently transboundary. Currents, migratory fish stocks and seafood trade do not conform to national boundaries.

Environmental risks do not respect maritime boundaries

As highlighted in my earlier research on marine environmental protection in the South China Sea, effective environmental governance therefore requires cooperation among ASEAN states and other Asia-Pacific states, including mechanisms for scientific research, information sharing, monitoring and coordinated responses to environmental threats.⁷ A nuclear-submarine accident

⁵ Junyang Zeng et al., "Public Dose Assessment for Yangjiang Nuclear Power Plant Effluents: A Multi-Media Numerical Model of Tritium Transport in the South China Sea," *Journal of Environmental Radioactivity* 286 (2025): 107684, <https://doi.org/10.1016/j.jenvrad.2025.107684>.

⁶ Sufen Ye et al., "Marine Ecological Risk Assessment Methods for Radiation Accidents," *Journal of Environmental Radioactivity* 180 (2017): 65–76, <https://doi.org/10.1016/j.jenvrad.2017.09.024>.

⁷ Julius Cesar Imperial Trajano et al., "Marine Environmental Protection in the South China Sea," *NTS Insight*, no. 2 (2018).

would add a particularly sensitive dimension to this challenge because environmental monitoring could intersect with questions of naval operations, national security and sovereignty.

For Southeast Asia, therefore, the concern is not simply whether a nuclear-powered submarine accident would cause measurable radioactive contamination. It is whether ASEAN has sufficient regional mechanisms to rapidly detect, assess, communicate and manage the environmental and socioeconomic consequences of such an incident. This points to the need for stronger regional cooperation on marine radiological monitoring, scientific data-sharing, seafood safety protocols, emergency response and public communication. Such measures would be consistent with the broader principle emerging from ASEAN and its collaborative mechanisms with its Dialogue Partners in the Asia-Pacific on marine environmental cooperation: environmental risks that cross maritime boundaries require cooperative governance even when the underlying security environment remains politically contested.⁸

Pathways to strengthening nuclear emergency preparedness through ASEANTOM and regional cooperation

ASEANTOM: ASEAN's regional nuclear governance platform

The expansion of civilian nuclear activities in Southeast Asia, alongside the increasing presence of nuclear-powered vessels in regional waters, makes nuclear emergency preparedness and response (EPR) an increasingly important dimension of ASEAN's nuclear governance. The ASEAN Network of Regulatory Bodies on Atomic Energy (ASEANTOM) provides an established institutional platform for addressing these challenges. ASEANTOM is an official ASEAN sectoral body under the ASEAN Political-Security Community and provides a framework for cooperation among national nuclear regulatory authorities on nuclear safety, security and safeguards. It also serves as an important regional point of contact with the International Atomic Energy Agency (IAEA).⁹

ASEANTOM's mandate already provides an important foundation for regional EPR cooperation. Its scope includes nuclear emergency preparedness and response and environmental radiation monitoring, alongside nuclear security, nuclear forensics and measures against illicit trafficking of nuclear and radioactive materials. It also promotes mutual information exchange as a confidence-building measure and supports the implementation of IAEA standards at the regional level.¹⁰ These functions provide a basis for moving beyond predominantly national approaches towards a more integrated regional preparedness architecture.

⁸ Trajano et al., "Marine Environmental Protection in the South China Sea."

⁹ Safety, Health and Environment National Authority (SHENA), "12th ASEAN Network of Regulatory Bodies on Atomic Energy (ASEANTOM) Annual Meeting," August 11, 2025, <https://shena.gov.bn/media-center/news/12th-asean-network-of-regulatory-bodies-on-atomic-energy-aseantom-annual-meeting>.

¹⁰ Mely Caballero-Anthony and Julius Cesar I. Trajano, eds., *Nuclear Governance in the Asia-Pacific* (Routledge, 2023), <https://doi.org/10.4324/9781003203360>.

Operationalising the ASEAN protocol on emergency preparedness and response

A particularly important instrument is the ASEAN Protocol for Preparedness and Response to a Nuclear or Radiological Emergency. The Protocol provides a regional framework for cooperation when a nuclear or radiological emergency has potential transboundary consequences. Its importance lies not simply in establishing another set of procedures, but in providing ASEAN with a common basis for notification, information exchange, coordination and assistance during an emergency.¹¹ The Protocol should increasingly be treated as an operational instrument rather than simply a normative commitment. This means translating its provisions into national procedures, identifying competent authorities and contact points, and ensuring that relevant agencies understand their respective responsibilities before an incident occurs.

ASEAN should now focus on operationalising the Protocol through regular regional exercises. Tabletop and field exercises could simulate a range of scenarios, including an accident at a civilian nuclear facility, a radiological release during the transportation of radioactive materials, or an accident involving a nuclear-powered vessel in Southeast Asian waters. A maritime scenario would be particularly relevant given the region's extensive coastlines, archipelagic geography and dependence on marine resources. An exercise could test how ASEAN states would coordinate seawater and seafood monitoring, temporary fishing restrictions, public-health advisories, maritime controls and public communications following a suspected radiological release. Such exercises would identify institutional gaps before an actual emergency occurs.

Using AR/NEX 2026 as a regional learning mechanism

ASEANTOM's work also provides an important mechanism for reviewing national progress and translating regional cooperation into practical lessons. At the regional level, member states can use ASEANTOM meetings to report on their accomplishments under ongoing projects, share activities undertaken during their respective chairmanships, and identify areas where further capacity-building is required. In 2026, particular attention is being given to the ASEAN Nuclear Emergency Notification and Communications Exercise (AR/NEX 2026), ASEANTOM's flagship project for the year.

The exercise provides an opportunity to test and strengthen regional arrangements for nuclear emergency notification, information exchange and public communication, while identifying practical gaps in coordination among national authorities. Its outcomes and lessons learnt should feed directly into the further development of ASEAN's nuclear emergency preparedness and response mechanisms, including the implementation of the ASEAN Protocol for Preparedness and Response to a Nuclear or Radiological Emergency. In this sense, AR/NEX 2026 can serve not

¹¹ ASEAN Network of Regulatory Bodies on Atomic Energy, *ASEAN Protocol for Preparedness and Response to a Nuclear or Radiological Emergency* (ASEAN Network of Regulatory Bodies on Atomic Energy, 2023), https://asean.org/wp-content/uploads/2023/09/ASEAN-Protocol-on-EPR_.pdf.

merely as an exercise, but as a regional learning mechanism for strengthening ASEAN's collective readiness to manage a future transboundary nuclear or radiological incident.¹²

Harnessing ASEANTOM's technical working groups

ASEANTOM's technical working-group structure provides an important mechanism for implementing this approach. Its five working groups cover radiological and nuclear security; hazard assessment and radiological dispersion modelling; radiation monitoring; emergency preparedness and response; and public emergency communications. Taken together, these capabilities address the principal components of an effective regional response: identifying the source of an incident, modelling the potential spread of contamination, detecting radiation, coordinating emergency measures and communicating credible information to affected populations.¹³

Strengthening regional radiation monitoring and data sharing

Regional radiation monitoring and data sharing should be another priority. ASEAN is already pursuing an Early Warning Radiation Monitoring Network (EWRMN) and ASEAN Radiation Data Exchange Platform, while current projects also seek to strengthen response capabilities and technical capacity in radiation monitoring and dose assessment.¹⁴ These initiatives could provide the technical backbone for implementing the ASEAN Protocol. Their value would be greatest during an incident where radiation or contamination could cross maritime or land borders and where individual states require rapid access to measurements from neighbouring countries.

Coordinating public communication

Public communication is equally important. A nuclear or radiological emergency can generate economic and social disruption even when actual radiation exposure is limited. Uncertainty over the safety of seafood, drinking water or agricultural products can lead to consumer avoidance, trade restrictions and loss of livelihoods. ASEAN should therefore develop common principles for communicating radiation risks and emergency measures, while allowing national authorities to retain responsibility for public messaging. The existence of a dedicated ASEANTOM working group on Public Emergency Communications provides an institutional basis for this effort.¹⁵

¹² Department of Science and Technology (Philippines), "PHL Leads ASEAN Cooperation on Nuclear Safety and Security at Inaugural Session of 13th ASEANTOM," August 13, 2026, <https://www.dost.gov.ph/knowledge-resources/news/4473-phl-leads-asean-cooperation-on-nuclear-safety-and-security-at-inaugural-session-of-13th-aseantom.html>.

¹³ Auzan Shadiq, "The Development of Technical Working Groups of ASEANTOM in Strengthening the Regional Cooperation Mechanism on Emergency Preparedness and Response in Southeast Asia," conference presentation, International Conference on Nuclear and Radiological Emergencies: Building the Future in an Evolving World, December 2025, <https://doi.org/10.13140/RG.2.2.15287.38561>.

¹⁴ Shadiq, The Development of Technical Working Groups of ASEANTOM in Strengthening the Regional Cooperation Mechanism on Emergency Preparedness and Response in Southeast Asia."

¹⁵ Department of Science and Technology (Philippines), "PHL Leads ASEAN Cooperation on Nuclear Safety and Security at Inaugural Session of 13th ASEANTOM."

Common approaches to communicating radiation measurements, health risks, protective measures and scientific uncertainty could help prevent inconsistent messaging from exacerbating public anxiety and economic disruption.

Building an ASEAN nuclear emergency preparedness ecosystem

Finally, ASEAN needs to address uneven national capacities. Member states differ considerably in regulatory expertise, radiation-monitoring infrastructure, emergency-response capabilities and human resources. ASEANTOM's emphasis on training, technical collaboration and the exchange of regulatory experience provides a pathway for reducing these gaps. Regional cooperation should also continue to draw on the IAEA, ASEAN dialogue partners and other technical networks, while progressively ensuring that core regional capabilities are sustained through ASEAN member-state resources.

The broader objective should be to develop an ASEAN nuclear emergency preparedness ecosystem in which national authorities retain primary responsibility but operate within a predictable regional framework for notification, monitoring, information exchange, technical assistance and coordinated response. This becomes particularly important as ASEAN considers new nuclear technologies, including small modular reactors (SMRs) and micro-modular reactors, for which ASEANTOM is already considering regional cooperation projects. ASEAN's preparedness architecture should therefore advance ahead of nuclear deployment – not in response to the first major transboundary emergency. Strengthening the ASEAN Protocol, operationalising ASEANTOM mechanisms and conducting regular multinational exercises would allow the region to ensure that the benefits of nuclear technology do not outpace the institutions needed to manage its risks.

National initiatives and the remaining maritime preparedness gap

Southeast Asian countries are strengthening national nuclear and radiological emergency preparedness through regulatory capacity-building, radiation monitoring, technical training and bilateral and regional cooperation. These initiatives provide an increasingly important foundation for responding to a future nuclear or radiological incident, but they are generally designed around land-based facilities, radioactive sources and national emergency-response systems (Table 1). This creates a potential gap when considering a maritime incident involving a nuclear-powered submarine or other nuclear-powered vessel, where the source of the hazard may be mobile, offshore, associated with military activities and potentially located outside the jurisdiction of the affected state.

Vietnam

Vietnam, for example, has been strengthening its emergency-response capacity through both national training and regional cooperation. In March 2025, the Dalat Nuclear Research Institute hosted an IAEA-supported regional workshop on developing protection strategies for nuclear or radiological emergencies, bringing together participants from 12 countries. The workshop

addressed hazard assessment, radiological dispersion modelling, emergency response criteria, technical facilities, human resources and coordination among relevant organisations. Vietnam has also undertaken environmental radioactivity-monitoring cooperation with Japan. These efforts are particularly relevant as Vietnam prepares for potential future nuclear power development. However, the protection strategies and training described in these initiatives are primarily oriented towards nuclear and radiological emergencies within conventional national emergency-planning frameworks.¹⁶

The Philippines

The Philippines has similarly used regional exercises to strengthen preparedness. Its nuclear and radiological institutions have participated in ASEAN-level drills designed to test notification, communication and emergency-response arrangements. Such exercises are valuable because they move preparedness beyond technical capability towards inter-agency and cross-border coordination. They can also help identify weaknesses in how information is transmitted between nuclear regulators, emergency services and government decision-makers.¹⁷ Nevertheless, a maritime submarine scenario would introduce additional actors – including coast guards, navies, maritime authorities, fisheries agencies and port authorities – that are not necessarily central to conventional nuclear emergency planning.

COUNTRY	EXISTING PREPAREDNESS INITIATIVE	WHAT IT STRENGTHENS	POTENTIAL VALUE FOR A MARITIME EMERGENCY	REMAINING GAP
Vietnam	IAEA-supported regional workshop on protection strategies; environmental radioactivity monitoring cooperation with Japan	Hazard assessment, dispersion modelling, emergency planning, technical expertise	Could support regional modelling and environmental monitoring following an offshore release	Preparedness remains primarily focused on conventional national nuclear/radiological emergencies rather than mobile maritime sources
Philippines	Participation/ leadership in ASEAN nuclear emergency exercises	Notification, communications, inter-agency coordination	Strong basis for testing cross-border notification and response	Maritime scenarios would require greater involvement of coast guards,

¹⁶ Dalat Nuclear Research Institute, “Regional Workshop on Developing a Protection Strategy for a Nuclear or Radiological Emergency,” April 3, 2025, <https://nri.gov.vn/en/regional-workshop-on-developing-a-protection-strategy-for-a-nuclear-or-radiological-emergency.html>.

¹⁷ Philippine Nuclear Research Institute, Department of Science and Technology, “PH Leads ASEAN Drill to Boost Nuclear Emergency Preparedness,” July 15, 2026, <https://www.pnri.dost.gov.ph/index.php/2-uncategorised/897-ph-leads-asean-drill-to-boost-nuclear-emergency-preparedness>.

COUNTRY	EXISTING PREPAREDNESS INITIATIVE	WHAT IT STRENGTHENS	POTENTIAL VALUE FOR A MARITIME EMERGENCY	REMAINING GAP
				navy, fisheries, ports and maritime authorities
Indonesia	BRIN–KAERI cooperation on radioactivity monitoring and nuclear preparedness	Radiation detection, scientific assessment, technical capacity	Particularly valuable given Indonesia’s archipelagic geography and extensive maritime domain	Need to integrate marine monitoring and maritime agencies into nuclear emergency response
Singapore	Enhancing capabilities for monitoring baseline environmental radiation levels and conducting radioactive plume dispersion modelling, including predictive modelling and impact assessment.	National emergency planning, environmental radiation monitoring, radioactive plume modelling, predictive impact assessment and inter-agency preparedness	Strong potential for early detection, plume modelling and impact assessment following a radiological release affecting Singapore or its surrounding waters	Limited experience with an offshore nuclear emergency involving a nuclear submarine vessel
Malaysia	IAEA Asia-Pacific nuclear security equipment hub and regional capacity-building	Radiation detection, equipment deployment, training	Could provide equipment and technical support following a regional radiological incident	Existing hub is designed primarily around nuclear security/radiological threats, not submarine accident response

TABLE 1. NATIONAL EMERGENCY PREPAREDNESS EFFORTS

Indonesia

Indonesia is also strengthening its capabilities through radiation monitoring and cooperation with international partners. Recent collaboration between Indonesia’s National Research and Innovation Agency (BRIN) and South Korea’s Korea Atomic Energy Research Institute (KAERI)

has focused on radioactivity monitoring and nuclear preparedness, demonstrating the importance of developing scientific capabilities for detecting and assessing environmental radiation.¹⁸

Singapore

Singapore, meanwhile, signed a 2026 memorandum of understanding with Indonesia's Nuclear Energy Regulatory Agency (BAPETEN) covering nuclear safety, security, safeguards and radiation protection, including joint training, personnel exchanges, research partnerships and technical meetings.¹⁹ Singapore has also strengthened its national nuclear and radiological emergency preparedness following the Fukushima Daiichi Nuclear Power Plant accident. In response, Singapore developed a national response plan based on a Fukushima-like scenario, which was reviewed by an IAEA Expert Mission in April 2018. The plan was subsequently enhanced to incorporate the Mission's recommendations. As regional interest in nuclear energy has grown, Singapore has continued to strengthen its nuclear incident preparedness capabilities. These include establishing baseline measurements of environmental radiation and developing radioactive plume dispersion modelling capabilities. Singapore can now undertake predictive modelling and impact assessments to support emergency preparedness and response to radiological incidents.²⁰ However, adapting them to an offshore incident involving a nuclear-powered submarine would require additional capabilities for marine radiation monitoring, seawater and seafood sampling, marine dispersion modelling, and coordination among nuclear, maritime, environmental, fisheries and security authorities.

Malaysia

Malaysia offers another important regional capability. It hosts the IAEA's only Asia-Pacific nuclear security equipment repository, which stores radiation detection equipment that can be deployed to countries requiring assistance and also serves as a regional training and capacity-building hub. This represents a valuable regional resource for detecting and managing radiological threats.²¹ But it is not currently designed to respond to nuclear submarine accidents.

Recommendations

These national initiatives demonstrate that Southeast Asia is not starting from a position of institutional weakness. Countries are developing monitoring systems, emergency plans, technical

¹⁸ Badan Riset dan Inovasi Nasional (BRIN), "BRIN-KAERI Collaboration on Radioactivity Monitoring and Nuclear Preparedness," February 12, 2026, <https://www.brin.go.id/en/news/126719/brin-kaeri-kolaborasi-pemantauan-radioaktivitas-dan-kesiapsiagaan-nuklir>.

¹⁹ Sean Ler, "Singapore, Indonesia Sign Nuclear Regulatory Cooperation Agreement," *AsiaOne*, July 1, 2026, <https://www.asiaone.com/singapore/singapore-indonesia-nuclear-regulatory-cooperation>.

²⁰ Republic of Singapore, "National Report on the Implementation of Obligations under the Convention on Nuclear Safety: Tenth National Report," International Atomic Energy Agency, September 2025, https://www.iaea.org/sites/default/files/singapore-10th-cns-national-report-vf_sg1.pdf.

²¹ Malay Mail, "Malaysia Hosts IAEA's Only Asia-Pacific Nuclear Security Equipment Hub, Bolstering Global Preparedness," *Malay Mail*, July 20, 2026, <https://www.malaymail.com/news/malaysia/2026/07/20/malaysia-hosts-iaeas-only-asiapacific-nuclear-security-equipment-hub-bolstering-global-preparedness/228280>.

expertise and bilateral mechanisms, while ASEAN and the IAEA provide platforms for regional coordination. The limitation is that much of this preparedness architecture remains organised around fixed nuclear facilities or radioactive-material incidents, whereas a submarine accident would present a fundamentally different operational problem. A vessel could be hundreds of kilometres offshore, the location and condition of its reactor could initially be uncertain, and access to the accident site could be complicated by military considerations and maritime jurisdiction. Moreover, an incident could require simultaneous monitoring of seawater, sediments and fisheries, while governments would need to assess potential consequences for coastal communities and seafood supply chains.

- **The priority, therefore, should be to adapt existing national and ASEAN preparedness mechanisms rather than create an entirely separate system.** Future ASEAN exercises could incorporate nuclear-powered submarine accident scenarios, linking ASEANTOM and national radiation authorities with maritime, environmental, health, fisheries, coast guard and foreign-affairs agencies. This would test whether existing notification and communication mechanisms can function when the source is mobile, offshore and potentially military in nature. Strengthening this maritime dimension would allow ASEAN to build on the substantial progress already made in national nuclear emergency preparedness while addressing an increasingly relevant regional risk.
- **There is a need to integrate nuclear-powered submarine scenarios into ASEANTOM exercises.** Future ASEANTOM exercises, including the AR/NEX, should incorporate scenarios involving an accident, fire, collision or grounding of a nuclear-powered submarine or vessel. Exercises should test not only nuclear regulators but also coast guards, navies, maritime authorities, environmental agencies, fisheries authorities, health ministries and foreign ministries.
- **ASEANTOM can expand regional radiation-monitoring cooperation to Southeast Asian waters.** Existing ASEANTOM initiatives on radiation monitoring and data exchange should be extended to include marine radiation monitoring. ASEAN could develop a regional baseline of background radiation in strategically important maritime areas and establish procedures for sharing seawater, sediment and seafood monitoring data following a suspected incident.
- **Nuclear power regulatory agencies should strengthen cooperation with maritime and environmental institutions.** ASEANTOM should develop closer working relationships with relevant ASEAN mechanisms dealing with maritime security, marine environmental protection, fisheries and disaster management. A nuclear-submarine accident would not be solely a nuclear-regulatory problem. It could simultaneously become a maritime, environmental, public-health, food-security and diplomatic crisis.