WORLD OCEAN FORUM 2023

Challenges for Successful Commercialization of Nuclear-Powered Merchant Ships, and Related Regulatory Status

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KR's Green-Ship to Carbon Neutra

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- **O II.** Novel Concept of Nuclear-Powered Ship Operation
- III. Public Acceptance for SMR Operations at Sea
- IV. Regulatory Regime for Nuclear-Powered Ships
- V. Safety Assessment Procedure for SMRs at Sea

Regulatory Status of Nuclear-Powered Merchant Ships

- **O** I. IMO Conventions and Codes
- **O II.** Government Rules and Regulations UK
- III. Government Rules and Regulations KOREA



CHALLENGES for Nuclear-Powered Merchant Ships

Past Experiences of Nuclear-Powered Ships

Representative Three Cases (excepting Russians')



1. NS Savannah (USA)

- World's first n-powered ship
- Passenger-cargo ship (181 m)
- DWT 10K tons & 100 passengers
- Single 74 MW reactor (PWR)
- 1962 ~ 1972 in service
- 90M USD cost, but 12M income

Low economic feasibility Low reliability Conflict among the crew

Past Experiences of Nuclear-Powered Ships

Representative Three Cases (excepting Russians')



2. NS Otto Hahn (Germany)

- World's second n-powered ship
- Ore carrier (172 m) & DWT 14K tons
- Single 38 MW reactor (PWR)
- 1968 ~ 1979 in service (1.2M km)
- 1979~2009 operated with diesel fuel
- 33 ports and 22 countries

Frequent docking refusal Limited shipping routes Excessive OPEX

Past Experiences of Nuclear-Powered Ships

Representative Three Cases (excepting Russians')



3. NS Mutsu (Japan)

- Test ship for nuclear power system
- General cargo ship (130 m)
- Single 36 MW reactor (PWR)
- 1968 (delivery), 1972 ~ 1992 test runs
- Radioactivity leak from the start
- Totally 1.2B USD cost

Shield design deficiency Strong civil complaint No commercial voyage

Nuclear-Powered Ship Commercialization





I. Cost-Effective and Marine-Applicable SMRs



Lifetime cost effectiveness: Nuclear > LNG > Diesel (minimum LCC before 15 years)

- Narrow and isolated space for reactor installation
- Harsh environment and isolated operation at sea
- Ship collision or grounding accidents
- Structural damage due to long-term neutron impact
- Effective fuel element design for long core life is required.
- Falling by the gravity of the control rod may not be reliable as a shutdown method.

There is a need to develop small nuclear reactors that are economically feasible throughout the life cycle of a ship and are applicable to the marine environment.

II. Novel Concept of Nuclear-Powered Ship Operation



- Reactor operations, inspection and maintenance at sea, by who?
- Reactor commissioning, by who?
- Reactor decommissioning, by who?
- Nuclear fuel ownership?
- Nuclear fuel supplier?
- Nuclear waste disposal?

Considering the characteristics of the nuclear reactors and the existing nuclear industry, the concept of life cycle operation of N-powered vessels must be newly established.

III. Public Acceptance for SMR Operations at Sea



- Nuclear reactor operations within the area close to daily life
 - public fear of radioactivity
 low public acceptance
 - ban of sailing in coastal areas and port entry
 - civil complaints and protest from local residents
 - political debate and liability

In order to enable the continuous operation of N-powered vessels in common maritime spaces, it is necessary to change the general public's perception of radioactivity positively.

IV. Regulatory Regime for Nuclear-Powered Ships



- Maritime industry is regulated by (world-wide)
 - local governments & IMO
- Nuclear industry is regulated by (regional)
 - local governments & IAEA
- International regulation needs
 - free navigation and port entry between multiple countries
 - unified and consistent international regulations

In order to maintain the legal operation of N-powered vessels worldwide, an integrated global licensing and regulatory system must be established for land and sea.

V. Safety Assessment Procedure for SMRs at Sea



- External accidents: ship collision, flooding, grounding, capsizing, fire/explosion, etc.
- Environmental conditions: ship motions, humidity, salt, independent operation, etc.
- Nonproliferation and control issues: piracy, ship and port security, etc.
- Consequences: passengers, crew, general public, radioactive marine pollution, etc.

There is a need to establish a new customized safety assessment procedure for N-powered vessels by integrating risk assessment technologies on land and at sea.

Interrelationship Between Five Challenges





REGULATORY STATUS of Nuclear-Powered Merchant Ships

Current Regulations for Nuclear-Powered Ships



IMO Conventions and Codes

- 1974 SOLAS Ch. VIII
- 1981 Nuclear Ship Code (Res. A.491(XII))

National Regulations

- [UK] Merchant Shipping (Nuclear Ships) Regulations 2022
- [UK] Marine Guidance Note 679 (M) Nuclear Ships 2022
- [KR] Nuclear Ships Regulations 2009 (revised in 2020)

Industry Standards To be developed

[IMO] SOLAS 1974 Convention Chapter VIII

Enacted in 1974

Effective Date 5/25/1980 CHAPTER VIII NUCLEAR SHIPS Regulation 1 Application fhis Chapter applies to all nuclear ships except ships of war. Title SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 2 Effective Date S/25/1980 Regulation 2 Application of other Chapters he Regulation scontained in the other Chapters of the present Convention apply to nuclear ships of nodified by this Chapter. * Refer to the Code of Safety for Nuclear Merchant Ships(resolution A491000) which sup requirements of this chapter. Title SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Title SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention / Chapter VIII (Reg.1–12) / Reg. 3 Effective Date SOLAS 1974 Convention /	except as
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Title COLAS 1074 Convention / Chanter VIII (Dec 1-12) / Dec 4	
Effective Date 5/25/1980	
Regulation 4	
Approval of Peactor Installation	
Approval of Reactor Installation	
The design, construction and standards of in inspection and assembly of the reactor installation sha the approval and satisfaction of the Administration and shall take account of the limitations which on surveys by the presence of radiation.	Il be subject to will be imposed

- International convention for nuclear ships
- It only covers nuclear-powered merchant ships.
- 12 regulations in a few pages
- Reg. 4 Approval of reactor installation F.S. govt.
- Reg. 5 Suitability for service on board ship
- Reg. 6 Ensuring no nuclear hazards F.S. govt.
- Reg. 7 Approval of safety assessment F.S. & P.S. govt.
- Reg. 8 Approval of operating manual F.S. govt.
- Reg. 9 Survey based on safety assessment ^{F.S. govt.}
- Reg. 10 Nuclear ship safety certificates F.S. govt. annual
- Reg. 11 Special control for radiation hazards P.S. govt.
- Reg. 12 Immediate accident report F.S. & P.S. govt.
- Principles on nuclear ship safety and survey

[IMO] Res. A.491(XII) Code of Safety for Nuclear Merchant Ships

Adopted in 1981



- so-called 'Nuclear ships code'
- Guide to the Administrations on internationally accepted safety standards for nuclear ships
- 8 chapters and 6 appendices (over 100 pages)
 - Ch. 1 Safety principles, risk acceptance, equivalents ...
 - Ch. 2 Design, safety functions, accident evaluation ...
 - Ch. 3 Structure, subdivision, LSA, fire safety, security ...
 - Ch. 4 Reactor core and control, coolant, interface ...
 - Ch. 5 Machinery and electrical systems
 - Ch. 6 Radiation safety (protection, dosimetry, waste ...)
 - Ch. 7 Operation, maintenance, manning, training ...
 - Ch. 8 Surveys (const., trials, operations, repairs ...)
 - App. Safety assessment, quality assurance ...
- It covers nuclear plants with PW type reactors.
- It is based on a philosophy of the DiD concept.

[UK] Merchant Shipping (Nuclear Ships) Regulations 2022

Enacted in 2022

Changes to le Merchant Shipp	ing (Nuclear Shipz) Regulati	y no oxoon outstanding effects for the 1 he ions 2022. (See end of Document for details)	
	STATUTORY IN	ISTRUMENTS	
	2022 N	0. 1169	
N	IERCHAN	T SHIPPING	
	SAF	ETY	
The Merchant	Shipping (Nuc	lear Ships) Regulations 2022	
Mada		15th November 2022	
Made Laid b	efore Parliament	16th November 2022	
Comin	g into force	8th December 2022	
The Secretary of State is sa 1995(1), that it is necessary they require ships to carry q	tisfied, for the purpos or expedient, in the in ualified seamen.	es of section 47(2) of the Merchant Shipping Act iterests of safety, to make Regulations in so far as	
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	PAF	RT 1	
	Prelin	ninary	
Citation, commencement,	extent and amendme	ents	
1.—(1) These Regulatio 2022 and come into force of	ns may be cited as the a 8th December 2022.	Merchant Shipping (Nuclear Ships) Regulations	
(2) These Regulations en	ctend to England and	Wales, Scotland and Northern Ireland.	
 1995 c. 21. For amendments, 9 Sections 47A and 47B were any by the Merchant Shipping and anneaded by the Britsh Overne 2015 (c. 20), section 106. Ther 2015 (s. 20), section 106. Ther and 51. 1292/2844, 4 S.I. 1998/1500. 	ee footnote (b) below. There erted by the Marine Navigati Maritime Security Act 199 is a se other amendments but mended by the Marine and G	are other samediag independents but none is referent. on Act 2011 (c 23), section 10. Sections 55 and 56 were summinded (r c 23), sections 13 arX(r) and Schedule 7. Section 25 was section 2013. Section 2064, was inserted by the Deregulation Act Constal Access Act 2009 (c. 23), Schedule 4, Part 1, paragraph 3	

- Implementation of SOLAS Ch. 8 & Nuclear Code
 - for commercial ships UK-flagged or within UK waters
 - applied with the Merchant Shipping Acts (1995)
- 6 parts and 34 articles (over 20 pages)
- Radiation safety: REPPIR over the Nuclear Code
- Approval of the Secretary of State
 - reactor installation, safety assessment, operating manual, manning and training, surveys, etc.
- Documents on board
 - safety certificates, crew certificates, safety assessment, operating manual, radiation emerg. plan, records of survey/test/repair, radioactive waste management, etc.
- Nuclear ship safety certificates (passenger/cargo)
 - UK regulation & 1974 SOLAS Ch. 8 & Nuclear Code
 - to be updated every year, kept on board, and submitted to the port authorities in advance

REPPIR: Radiation (Emergency Preparedness and Public Information) Regulations 2019

[UK] Marine Guidance Note 679 (M) Nuclear Ships

Enacted in 2022

203 Maritime & Coastguard Agency MARINE GUIDANCE NOTE MGN 679 (M) Nuclear Ships Notice to all Shipowners, Operators, Masters, Officers, Maritime Administrations, Port Authorities and Recognised Organisations This notice should be read with the Merchant Shipping (Nuclear Ships) Regulations 2022 Summarv This notice provides guidance on the application of the Merchant Shipping (Nuclear Ships) Regulations 2022 (SI 2022/1169), which regulate UK commercial nuclear-powered ships and foreign commercial nuclear-powered ships visiting UK waters. The guidance covers the following aspects: Approvals and surveys Reactor Installation Safety Assessment Quality Assurance Programme Operating Manual Radiation Safety Manning and Training Ports · Decommissioning of nuclear-powered ships · Offences and penalties Detention 1. Introduction/background This notice provides guidance on the application of the Merchant Shipping Ships) Regulations 2022 (SI 2022/1169) ("the 2022 Regulations"), which implement Chapte VIII in the Annex to the International Convention for the Safety of Life at Sea, 1974 (SOLAS) relating to commercial nuclear-powered ships. The 2022 R

ONR: Office for Nuclear Regulation

- Guidance on the application of the Merchant Shipping (Nuclear Ships) Regulations 2022
- 13 sections and 1 annex (dozens of pages)
- the role of ONR (UK Nuclear Regulator) specified
 - reactor construction and maintenance on land
 - nuclear site license required
- The MCA may grant authority to an RO.
 - statutory surveys, design appraisal, safety assessment appraisal and certification
- Safety assessment, Quality assurance program, Operating manual, Radiation Safety, Manning



MCA: Maritime and Coastguard Agency

[KOREA] Nuclear Ships Regulations

Enacted in 2009 and revised in 2020

원자력선기준 [시행 2020, 7, 31.] [해양수산부고시 제2020-112호, 2020, 7, 31., 일부개정.] 해양수산부(해사산업기술과), 044-200-5836~7 ----제1조(목적) 이 기준은 선박안전법 제26조의 규정에 의한 원자력선의 구조 및 설비에 관하여 필요한 사항을 규정 하니 함을 목적으로 한다. 압력, 유 제2조(정의) 이 기준에서 사용하는 용어의 정의는 다음 각 호와 같다. 1. "원자력선"이라 함은 원자력 시설을 설비한 선박을 말한다. 하여야 한 2. "원자로 시설"이라 함은 원자로 설비, 핵연료물질 취급설비 및 방사선관리설비 등을 말한다. 3. "원자로 설비"라 함은 원자로 본체, 원자로 냉각장치, 원자로 제어장치, 원자로 격납용기 및 이들의 부속장치 를 막하다 치되어 있 4 "제어장치"라 함은 원자로에서 열중성자를 흡수하여 열중성자가 연료에 흡수되는 비율을 제어하여 핵분열 연 쇄반응을 조정하는 장치를 말한다. 톱벌브 또 5. "격납용기"라 함은 방사성 물질이 원자로 격납용기 내에 밀폐되어 외부에 방출되지 않도록 방호벽으로 만들 어진 용기를 말한다. 오염된 물 제3조(특수한 섬비) 이 기준의 규정에 적합하지 아니하거나 이 기준에서 규정되어 있지 아니한 특수한 섬비로서 해양수산부장관이 이 기준의 규정에 적합한 것과 동등이상의 효력이 있다고 인정하는 것에 대하여는 이 기준의 규정에 적합한 것으로 본다. 제4조(선체 구조 및 설비 통) ① 선체 재료는 내식성을 가지거나 적절한 방식조치를 한 것이어야 하며, 선체구조 필요가 있 는 충분한 강도를 가지는 구조의 것이어야 한다. ② 원자력선은 강선의 구조기준, 선박구획기준, 선박복원성 기준, 선박기관기준, 선박전기설비 기준, 선박방화구 을 공급할 조 기준, 선박소방설비 기준, 선박구명설비 기준 및 선박설비기준 등 선박시설기준을 만족하여야 한다. 제5조(원자로 장치의 승인) ① 원자로 장치의 설계, 구조, 검사 및 조립은 해양수산부장관으로부터 승인을 받아야 건원장치 하며, 방사선에 의하여 검사가 제약 받는 것을 고려하여야 한다. ② 원자로 장치는 일반적 또는 특별한 항해 여건에서 사용되는 운전 상태를 고려하여 선박에 적합하게 설치하 고하여야 여야 한다. 제6조(안전설명서 등) ① 원자력선의 탑승자, 물 및 음식물 등은 방사선에 의한 위험이 없도록 안전하여야 한다. 대하여 ② 원자력시설 및 선박의 안전을 평가할 수 있도록 안전설명서를 작성하여야 하며, 해양수산부장관은 안전설명 검토하여 서가 만족스럽게 작성된 경우 승인하여야 하며, 항상 최신화 되어 있어야 한다. 2009, 8, ③ 안전평가서는 원자력선이 입항하고자 하는 항만당국이 선박의 안전성을 평가 할 수 있도록 충분한 여유를 가지고 사건에 제공되어야 한다. 제7조(운전지침서) ① 원자력시설의 근무자에게 운전에 관한 정보 및 절차를 제공하기 위하여 운전지침서가 준비 되어야 한다. ② 해양수산부장관은 운전지침서가 만족스럽게 작성된 경우 승인하여야 하며, 항상 최신화 되어 있어야 한다. 제8조(검사 및 중서) ① 원자력선이 선박시설기준에 적합하고, 안전설명서 요건을 충족하여 선박검사에 합격한 경 우 원자력여적선안전증서 또는 원자력화물선안전증서를 발행할 수 있다. ② 선박검사는 1년에 1회 이상 실시하여야 한다. ③ 원자력여적선 안전증서와 원자력화물선 안전증서의 유효기간은 12개월을 초과하여서는 아니된다 제9조(특별한 통제) 원자력선의 탑승자, 물 및 음식물 등은 방사선에 의한 위험이 발생하지 아니할 것을 확인하기 위한 특별한 통제를 받아야 한다. 제10조(원자로 시설 등) ① 원자로 격납용기에 인접한 선체 부분은 충돌 및 좌초 등에 의해 원자로 격납용기의 성능 저하를 방지할 수 있는 것이어야 한다.

③ 원자로 격납용기가 있는 구획실은 해당 용기에서 내장한 장치가 손상된 경우에 과다한 방사성물질이 누출되 지 아니하여야 한다.

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- Korea's only nuclear ship regulation at present
- It covers nuclear-powered ships.
- 19 articles in 2 pages Based on the 1974 SOLAS Ch. VIII

However nuclear offshore facilities are not explicitly excluded.

- Approval from the Administration
 - Safety assessment To be kept on board and up-to-date
 - Operating manual To be submitted to PSC in advance for review
 - Reactor installation *Design, assembly and inspection*
 - Nuclear passenger ship safety certificate Valid for one year
 - Nuclear cargo ship safety certificate Valid for one year
 - Annual inspection is required
- Insufficient detail for practical application
- Special control for radiation hazards
- Immediate accident report to PSC and FSC

More Integrated and Practical Regulatory System Needed

IMO and Governments have to further improve or newly establish regulations for nuclear-powered ships to address the following issues.

- Further specific safety requirements
- Various SMR types, such as MSR, SFR, LFR etc.
- Operators: Ship vs Reactor
- Reactor decommissioning and radioactive waste
- Nuclear fuel supply chain (non-proliferation)
- Authority among the government departments
- Intergovernmental relationships











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