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Special Feature:
Trends and Initiatives toward Reduction of GHG

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Prefatory Note

Introduction to the Special Feature on "Trends and Initiatives toward Reduction of GHG"

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I would like to take this opportunity to welcome all our readers to this Special Feature of ClassNK Technical Journal No. 8 on "Trends and Initiatives toward Reduction of GHG ".

We publish the ClassNK Technical Journal to contribute to technical progress in the maritime industry by making the technological activities and research results of the Society available to all those concerned. Responding to recent remarkable increases in the size of container carriers, the previous issue, ClassNK Technical Journal No. 7, reported on revisions of the rules to enable safe and rational structural design and evaluation of container ships, and technical trends and recent research and development achievements focusing on support services for the operation of container ships.

The meeting of IMO MEPC80 (80th Session of the Marine Environment Protection Committee of the International Maritime Organization) held in July of this year adopted the 2023 IMO Strategy on Reduction of GHG Emissions from Ships as a revised strategy, in which the target of shipboard discharges ("Tank-to-Wake") in the initial strategy adopted in 2018 was changed to cover the full life cycle ("Well-to-Wake"). The level of the reduction target was also changed from the original minimum 50 % reduction by 2050 to net-zero emissions by around 2050, and strengthening of international regulations toward achievement of this significantly more ambitious target is underway. Accompanying initiatives to support of GHG reduction technologies, the Society is holding various types of seminars to promptly provide the most up-to-date information related to all those concerned.

This ClassNK Technical Journal No. 8, we have assembled a Special Feature entitled "Trends and Initiatives toward Reduction of GHG," which introduces international regulatory trends in connection with GHG emission reductions and technologies for achieving emission reductions, together with initiatives for evaluation and certification of GHG reduction performance. In addition, this issue also includes a diverse range of other articles and papers on various research and development achievements, the technical activities of the Society, and trends in the IMO.

Based on the needs of society and the industry, we will continue to make diligent efforts in research and development which contribute to ensuring the safety of human life and property at sea, protecting the marine environment and creating innovations that lead society in order to contribute to the further development of the maritime industry.

We sincerely request the continuing understanding and support of all those concerned in the future, as in the past.

Recent Topics on GHG Emissions Reduction from International Shipping

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1. INTRODUCTION

With the aim of achieving a global reduction of greenhouse gas (GHG) emissions, the Paris Agreement adopted in 2015 sets a common global goal of keeping the world's average temperature increase well below 2 °C compared to pre-industrial levels and making efforts to limit it to 1.5 °C.

Efforts to reduce GHG emissions in international shipping are being pursued by the International Maritime Organization (IMO). Since 2013, the IMO has introduced regulations in the form of the Energy Efficiency Design Index (EEDI) and the Energy Efficiency Existing Ship Index (EEXI), made it mandatory that ships have a Ship Energy Efficiency Management Plan (SEEMP), and established the Carbon Intensity Indicator (CII) rating system. Furthermore, in 2023, the IMO reviewed its GHG Strategy and set more stringent targets than the Initial IMO GHG Strategy adopted in 2018, and is now considering regulations to achieve these new targets.

On the other hand, to achieve net-zero GHG emissions by 2050, the European Union (EU) has decided to expand the EU Emissions Trading System (EU-ETS) to the maritime sector and also introduce the FuelEU Maritime regulation to promote decarbonization of fuels used in shipping.

Private sector initiatives are also underway in the maritime business. With these regulations and initiatives, efforts to reduce GHG emissions are expected to accelerate in the future.

This paper provides an overview of the regulations and schemes for GHG emissions reduction in the IMO and EU, as well as the latest discussions in this area.

2. TOPICS IN IMO

2.1 Revision of IMO GHG Strategy

Regarding the IMO strategy for reducing GHG emissions from international shipping, the 2018 IMO GHG Strategy (Initial IMO GHG Strategy) was adopted at the 72nd session of the Marine Environment Protection Committee (MEPC 72) held in 2018. This strategy outlined the vision and target levels for GHG emissions reduction from international shipping. It was agreed that this reduction strategy would be reviewed every five years. Subsequently, the 2023 IMO GHG Strategy (Revised IMO GHG Strategy), which strengthened the reduction targets summarized as follows (Table 1), was adopted at MEPC 80 in July 2023.

- Regarding marine fuels, the Initial IMO GHG Strategy focused only on emissions by onboard usage (Tank-to-Wake). However, under the Revised IMO GHG Strategy, emissions through the entire lifecycle from fuel production, transportation, and storage to onboard usage (Well-to-Wake) are to be taken into account.
- In the Initial IMO GHG Strategy, a vision which confirms IMO's commitment to reducing GHG emissions from international shipping was set as "*phase out GHG emissions as soon as possible in this century*". In the Revised IMO GHG Strategy, "*in this century*" was removed and "*as soon as possible*" was retained.
- The target for the total amount of GHG emissions in the Initial IMO GHG Strategy aimed to reduce the total annual GHG emissions by at least 50 % by 2050 compared to 2008. In the Revised IMO GHG Strategy, this target was changed to "*reach net-zero GHG emissions by or around, i.e., close to 2050*". The Revised IMO GHG Strategy also introduced indicative checkpoints to achieve this target, aiming to reduce total GHG emissions by at least 20 % compared to 2008 by 2030 and at least 70 % compared 2008 by 2040.
- The target for transport efficiency, i.e., CO_2 emissions per transport work, in the Initial IMO GHG Strategy aimed "*to reduce CO_2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008*". In the Revised Strategy, only the target of 2030, i.e., "*by at*

least 40% by 2030", was retained.

- The Revised IMO GHG Strategy introduced a new target related to the total energy used by international shipping relating to the uptake of zero or near-zero GHG emission technologies, fuels, and/or energy sources, which are to represent 5 %, striving for 10 %, by 2030.

The IMO will consider and implement regulations to achieve these targets outlined in the Revised IMO GHG Strategy.

Table 1　IMO GHG Strategy

	2018 Initial Strategy	2023 Revised Strategy
Scope of emissions	Onboard emissions (Tank-to-Wake)	Lifecycle emissions (Well-to-Wake) to be taken into account
Levels of ambition (Compared to 2008)	Reduce by at least 50 % by 2050 Phase out as soon as possible within the century	Reach net-zero GHG emissions by or around 2050 Peak GHG emissions as soon as possible (Indicative checkpoints) 2030: Reduce by at least 20 %, striving for 30 % 2040: Reduce by at least 70 %, striving for 80 %
Carbon intensity target (Compared to 2008)	2030: Reduce by at least 40 % 2050: Reduce by at least 70 %	2030: Reduce by at least 40 % (*1)
Introduction target zero-emission technologies, fuels and energy sources	---	2030: Represent at least 5 %, striving for 10 % (*2)

(*1) Indicator is CO_2 emission per transport work (Tank-to-Wake base)
(*2) Consumption energy base

Major Changes

- ✓ Reach net-zero GHG emissions by or around 2050.
- ✓ Consider not only onboard emissions, but also lifecycle emissions, including fuel production, transportation, and storage.
- ✓ Monitor progress in terms of total GHG emissions and adopt a target of increased uptake of zero or near-zero GHG emission technologies. fuels, and/or energy sources.

In order to contribute to encouraging broad discussions among stakeholders and accelerating efforts towards decarbonization of international shipping, ClassNK attempted to visualize the actions required by the Revised IMO GHG Strategy in quantitative terms by estimating the total GHG emissions, the scale of introduction of zero-emission fuels, and the scale of introduction of zero-emission fuel ships required to achieve the 2030 zero-emission fuels introduction target and GHG emissions reduction target in the Revised IMO GHG Strategy, applying to ships of 5000 gross tonnage and above engaged in international voyages (which are subject to IMO DCS). The Society summarized this information in a White Paper (Fig. 1), which can be accessed on ClassNK's website. ClassNK plans to continuously update its content through ongoing dialogue with stakeholders.

Fig. 1　White Paper

2.2 Guidelines on Lifecycle GHG Intensity of Marine Fuels

The IMO acknowledges the need to consider emissions through the entire lifecycle of low/zero-carbon fuels such as hydrogen, ammonia, and biomass-based fuels, which are expected to be more widely used in the future for the decarbonization of ships (Fig. 2). Furthermore, recognizing the significant impact on global warming of GHG other than carbon dioxide (CO_2), such as methane (CH_4) and nitrous oxide (N_2O), the IMO developed guidelines to comprehensively assess the GHG emission intensity (GHG emissions per unit of energy) through the entire lifecycle of fuels used in ships. The guidelines aim to evaluate the GHG emission intensity from marine fuels comprehensively through their production, distribution, and use onboard ships, and were adopted at MEPC 80 as "Guidelines on lifecycle GHG intensity of marine fuels (LCA guidelines)" (Resolution MEPC.376(80)).

The Guidelines provide a general framework for assessing the lifecycle GHG intensity of marine fuels. When evaluating GHG emissions through the lifecycle of a fuel, it will be necessary to follow the calculation methods and procedures outlined in the Guidelines. The Guidelines include the following aspects:

- Calculation methods for the GHG intensity for CO_2, methane (CH_4), and nitrous oxide (N_2O)
- Standardized format for a fuel lifecycle label that provides information on the characteristics of each fuel
- Method for specifying default values for the GHG intensity of representative fuels
- Third-party certification

However, the Guidelines also highlight the need for further examination of certain issues, such as inclusion of emissions resulting from land-use changes (e.g., conversion of forests to agricultural land) associated with the production of fuels derived from biomass, clarification of requirements related to certification methods, establishment of default values for GHG emissions intensity (currently only five types, including HFO, are specified), and development of guidance on third-party certification. Ongoing efforts to address these issues are planned, including expert workshops, to facilitate the practical implementation of the Guidelines.

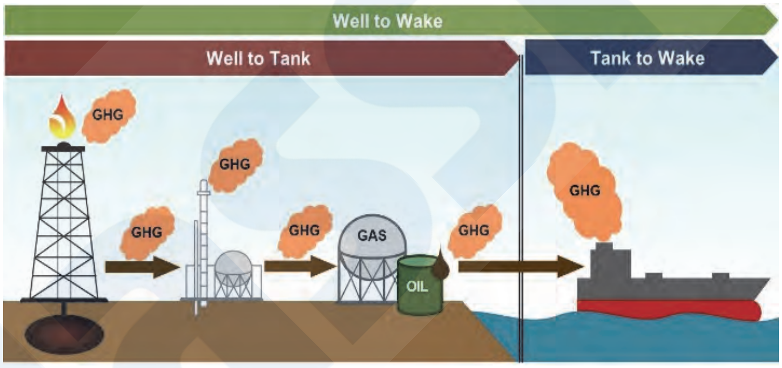

Fig. 2 GHG emissions through the entire lifecycle (WtW) of fuels

2.3 Mid-Term Measures for GHG Reduction

During MEPC 80, discussions were held on how to proceed with measures to achieve the GHG reduction targets outlined in the Revised Strategy. As a result, it was agreed that a basket of candidate measures should comprise both a technical element and an economic element. Specifically, it was agreed that the technical element should be based on the phased reduction of the GHG intensity of marine fuels, and the economic element should be based on the maritime GHG emission pricing mechanism. Candidate measures will be developed based on comprehensive impact assessments to evaluate the impact of these measures on individual countries (Table 2).

Furthermore, a timeline specifying adoption of specific mid-term measures by 2025, followed by entry into force by 2027, has been incorporated in the Revised IMO GHG Strategy (Table 3).

Table 2　Proposed mid-term measures

	Measures	Proposed by	Outline
Technical measures	GFS (GHG Fuel Standard)	EU Countries, EC	• Phased reduction of GHG intensity for fuels (gCO_2eq/MJ). • Based on lifecycle GHG emissions of fuels (**Well-to-Wake**). • Flexibility mechanisms (allocation of over-achievement to other ships or compliance by payment of contribution).
Technical measures	IMSF&F (International Maritime Sustainable Fuels and Fund)	China	• Phased reduction of GHG intensity for fuels (gCO_2eq/MJ). • Based on onboard emissions (**Tank-to-Wake**). • Flexibility mechanisms (allocation of over-achievement to other ships or compliance by payment of contribution).
Economic measures	Feebate	Japan	• Levy for GHG emissions and rebate for zero-emission fuels. • Revenue from levy: Support for **first movers** to accelerate the introduction of zero-emission ships.
Economic measures	GHG levy	Marshall Islands, Solomon Islands	• Levy on GHG emissions (100 USD per CO_2-ton). The amount of the levy will increase. • Revenue from levy: Support for **developing countries**.
Economic measures	F&R (Fund and Reward)	ICS (International Chamber of Shipping)	• Levy on CO_2 emissions. • Revenue from levy: Support for **first movers, developing countries, and R&D**.

(Prepared by ClassNK based on a report of MEPC 80 issued by MLIT in Japan.)

Table 3　Timelines for development and implementation

MEPC 81 (Spring 2024)	Finalization of basket of mid-term measures
MEPC 82 (Autumn 2024)	Finalization of comprehensive impact assessment
MEPC 83 (Spring 2025)	Approval of mid-term measures
Extraordinary session of MEPC (Autumn 2025)	Adoption of mid-term measures
16 months after adoption (2027)	Entry into force of mid-term measures

2.4　GHG Emissions Using Biofuels

From the perspective of GHG reduction, the international shipping industry has been gradually transitioning to alternative fuels, and discussions are underway at the IMO regarding the use of biofuels, which are renewable fuels with relatively easy applicability as “drop-in fuels” for existing ships.

Biofuels are produced from biomass, mainly plant oil, as the raw material. Although these fuels emit CO_2 during combustion, because the plants (biomass) used as the raw material absorb CO_2 in the atmosphere in their growth process, biofuels are regarded as “carbon-neutral” fuels in sectors other than the maritime industry. However, the IMO regulations do not provide clear guidance on how to account for the GHG reduction benefits of biofuels. Therefore, during MEPC 80, discussions were held on how biofuels should be treated within the IMO DCS and CII rating system, and how CO_2 emissions should be evaluated when biofuels are used. As a result, interim guidance titled “Interim guidance on the use of biofuels under regulations 26, 27, and 28 of MARPOL Annex VI (DCS and CII)” (MEPC.1/Circ.905) was approved until the handling of biofuels is clarified in the aforementioned LCA Guidelines.

According to the guidance, biofuels that have been certified by an international certification scheme, meeting its sustainability criteria, and that provide a well-to-wake GHG emissions reduction of at least 65 % compared to the well-to-wake emissions of fossil MGO of 94 [gCO_2eq/MJ] (i.e., emissions intensity not exceeding 33 [gCO_2eq/MJ]) according to that certification, CO_2 emission conversion factor (Cf) equal to the value of the well-to-wake GHG emissions of the fuel according to the certificate (expressed in gCO2eq/MJ) multiplied by its lower calorific value can be used in the calculations for IMO DCS and CII.

Biofuels that do not meet these conditions should be assigned a Cf equal to the Cf of the equivalent fossil fuel type.

3. TOPICS IN EUROPEAN REGULATIONS

3.1 EU-ETS Directive

3.1.1 Background

The European Union (EU) has set a target of reducing GHG emissions by 55 % or more from the 1990 level by 2030 with the aim of achieving net-zero emissions by 2050. In July 2021, a comprehensive climate change policy package “Fit for 55” was announced to achieve the 2030 target, and a proposal to expand the EU Emissions Trading System (EU-ETS), which is a carbon pricing system, to the shipping sector was also announced. Subsequently, the European Parliament adopted the relevant legislation of Fit for 55 on 18 April 2023, including the application of the EU Directive (hereinafter referred to as “EU-ETS Directive”) to the shipping sector, and the European Council adopted the legislation on 25 April 2023, completing the legislative process. Accordingly, it was decided that the EU-ETS would start in the shipping sector from 1 January 2024. In addition, amendments in connection with the application of the EU-ETS Directive were also adopted in the EU-MRV Regulation, which is a monitoring, reporting, and verification system for ship fuel consumption that was introduced in 2018 for ships calling at EU ports.

3.1.2 Application of EU-ETS Directive

The EU-ETS will apply from 1 January 2024 to vessels of 5 000 GT and above calling at ports within the jurisdiction of EEA Member States, irrespective of the country of registry. (EEA: European Economic Area; in addition to the 27 EU member states, the EEA also includes Norway, Iceland, and Liechtenstein, for a total of 30 countries.) Beginning 1 January 2025, the EU-ETS will be extended to general cargo ships of 400 GT and above but less than 5 000 GT. The term “port call” as used in these regulations means a port call for cargo handling, passenger boarding or disembarking, or to relieve the crew of an offshore vessel. An anchorage for any other purpose (refueling, obtaining supplies, etc.) and at some container transshipment ports is not considered a port call.

The target gases for GHG emissions are CO_2 until 2025, and CO_2, methane (CH_4)) and nitrous oxide (N_2O) after 2026.

The total GHG emissions for the following voyages are applicable.

・50 % of emissions from ships sailing between ports of call under the jurisdiction of an EEA Member State and ports of call outside the jurisdiction of an EEA Member State
・100 % of emissions from ships sailing from ports of call under the jurisdiction of an EEA Member State and arriving at ports of call under the jurisdiction of an EEA Member State
・100 % of emissions from ships within ports of call under the jurisdiction of an EEA Member State

As a transitional measure, for the first two years after the introduction of the EU-ETS Directive, the emissions subject to the EU-ETS will be reduced as follows:

Emissions in 2024: 40 % of the total emissions in the scope
Emissions in 2025: 70 % of the total emissions in the scope

3.1.3 Obligations of Shipping Companies

After 2024, shipping companies are to purchase allowances equivalent to the annual GHG emissions indicated in paragraph 3.1.2. above and surrender them by 30 September of each year. After surrendering the required allowances, if the company has surplus emission allowances, the surplus can be sold or carried over to the next year.

These GHG emissions are verified based on the EU-MRV Regulation. In conjunction with the introduction of the EU-ETS, the revised EU-MRV system will require shipping companies to prepare monitoring plans corresponding to the EU-ETS, which are to be verified by a verifier, and to submit them to the administering authorities listed in paragraph 3.1.4. below by 1 April 2024. They will also be required to submit emissions reports to the administering authority, the flag state (if the flag state is an EEA Member State) and the European Commission by 31 March each year after 2025, after verification by the verifier against the previous year's data for the vessels concerned. Companies will also be required to submit the sum of their GHG emissions at the company level (aggregate emission data) to the administering authority by 31 March of each year.

3.1.4 Administering Authority

The applicable shipping companies are registered with one of the EEA Member States (administering authority), and regulatory compliance is confirmed by this administering authority. The criteria for registration with the administering authority are as follows:

(i) A shipping company registered in an EEA Member State: Registered with the administering authority of the EEA Member State in which the company is registered.

(ii) A shipping company not registered in an EEA Member State:

- Registered with the administering authority of the EEA Member State with the highest number of port calls of the shipping company's EU-related voyages in the last four years.
- Registered with the administering authority of the EEA Member State where the ship first arrived/first started a voyage after 2024 if it has not made a port call in the EU in the last four years.

A list of the competent authorities with which each shipping company is registered will be published by 1 February 2024.

3.1.5 Exception of Port of Call

Under the EU-ETS for shipping, "stops of containerships in a neighbouring container transhipment port" are excluded from ports of call, and "neighbouring container transhipment port" means "neighbouring container transhipment ports where the share of transhipment of containers, measured in twenty-foot equivalent unit, exceeds 65 % of the total container traffic of that port during the most recent twelve-month period for which relevant data are available located outside the Union but less than 300 nautical miles from a port under the jurisdiction of a Member State". This means that the voyages preceding and following such ports are considered to be consecutive voyages.

By 31 December 2023, a list of such container transhipment ports will be established by the European Commission.

3.1.6 Penalties

The excess emissions penalty is to be EUR 100 per tonne of carbon dioxide equivalent emitted, for which the shipping company has not surrendered allowances. Payment of the excess emissions penalty will not release the shipping company from the obligation to surrender an amount of allowances equal to those excess emissions when surrendering allowances for the following calendar year, and if a shipping company has failed to comply with the surrender requirements for two or more consecutive reporting periods and other enforcement measures have failed to ensure compliance, the competent authority of the Member State of the port of entry may issue an expulsion order.

3.2 FuelEU Maritime Regulation

3.2.1 Background

In the EU, CO_2 emissions from maritime transport to and from ports in the EEA account for about 11 % of CO_2 emissions from all transport sectors in the EU and 3 % to 4 % of total CO_2 emissions in the EU. Unless further measures are taken, CO_2 emissions from maritime transport are expected to increase. As described in paragraph 3.1.1, the comprehensive climate change policy package "Fit for 55" was announced to achieve the 2030 target, and in addition to the proposed expansion of the EU-ETS carbon charging system to the shipping sector described in paragraph 3.1, a draft FuelEU Maritime regulation was announced to promote decarbonization of fuels used in ships. Adoption by the European Parliament and the European Council was completed in July 2023, and introduction of the FuelEU Maritime regulation from January 2025 was decided.

3.2.2 Overview of FuelEU Maritime Regulation

FuelEU Maritime, like the EU-ETS, is a regulation that is commonly applied in the EEA Member States, regardless of the ship's flag. FuelEU Maritime is applied to companies.

The FuelEU Maritime regulation, which will be introduced in the EU/EEA Member States in 2025 to promote the decarbonization of fuels used on board ships, consists of two main provisions:

(1) Provisions setting a limit of the GHG intensity of energy used on board a ship

(2) Provisions requesting the use of on-shore power supply (OPS) or zero-emission technology in port (only containerships and passenger ships)

The outline of the above two provisions constituting FuelEU Maritime is as follows:

(1) Outline of provisions setting upper limits of GHG intensity of energy used on board ships

The GHG intensity provisions set upper limits for the annual average value of "GHG emissions per energy [gCO2eq/MJ]", which is called "GHG intensity", for fuels used on voyages to and from ports under the jurisdiction of EU/EEA Member States, as follows:

- Starts from 1 January 2025.
- Fuel used on board ships of over 5 000 GT arriving at or departing from EU/EEA ports are in the scope of FuelEU Maritime.

- The GHG intensity limit is assessed on a lifecycle (Well-to-Wake) basis.
- The annual average value of GHG intensity is calculated on a ship-by-ship basis.
- If the annual average value of GHG intensity exceeds the upper limit of GHG intensity for the year, the company concerned is considered to have complied with the regulation by paying a penalty (see paragraph 3.2.5.) corresponding to the GHG emissions [gCO2eq] multiplied by the energy consumption for the year.
- For the same vessel, GHG emissions for the achievement of the upper limit of GHG intensity can be carried forward to the next year (banking) or used ahead of schedule for achievement of the next year (borrowing), or “the achievement of the upper limit” and “the failure to achieve the upper limit” can be offset for multiple vessels in the fleet (pooling) in the same reporting period.

(2) Outline of provisions requiring the use of on-shore supply (OPS) or zero-emission technologies in port (only containerships and passenger ships)

- Starts from 1 January 2030. (For some ports, starts from 1 January 2035.)
- Containerships and passenger ships over 5 000 GT should use an on-shore power supply (OPS), etc., when moored in ports of EU/EEA Member States.
- There are some exemptions, e.g., the provisions are not applicable to mooring for less than 2 hours.

Failure to comply with this provision is deemed to be compliance by paying a penalty based on the amount of power, etc. during mooring.

3.2.3 Confirmation of GHG Intensity

The energy consumption and GHG intensity of ships covered by the FuelEU Maritime regulation are confirmed on the basis of data collected under the FuelEU Maritime monitoring plan (see paragraph 3.2.4.).

In FuelEU Maritime, GHG intensity is calculated on a Well-to-Wake basis. The GHG intensity of each fuel is calculated for the Well-to-Tank and Tank-to-Wake portions based on a specified coefficient, and the total value is the GHG intensity of the fuel on a Well-to-Wake basis. For example, in the case of marine diesel oil (MDO), the GHG intensity of the Well-to-Tank portion is 14.4 [gCO2eq/MJ] and that of the Tank-to-Wake portion is 76.4 [gCO2eq/MJ], and the total value of 90.8 [gCO2eq/MJ] is the GHG intensity of the fuel.

The upper limit of the GHG intensity is to be increased every 5 years based on the 2020 level of 91.16.

When multiple fuels are used, the weighted average of the energy used is the GHG intensity of the ship.

As a special incentive measure, the GHG intensity of non-biological renewable fuels (RFNBO, Renewable Fuels of Non-Biological Origin), such as ammonia fuel produced from hydrogen using renewable energy sources, is calculated as half of the original value. This special measure applies from 1 January 2025 to 31 December 2033.

In addition, when monitoring and reporting under FuelEU Maritime, the information and data collected under the EU-MRV Regulation are to be used as necessary. Details are expected to be published by the EU in the future.

3.2.4 FuelEU Monitoring Plan

By 31 August 2024, shipping companies are to submit to the verifier a “FuelEU Monitoring Plan”, which specifies a method for monitoring and reporting the amount of energy (fuel type and consumption) to be used by ships during navigation and berthing. For ships calling at a port in an EU/EEA Member State for the first time after 31 August 2024, the monitoring plan must be submitted to the verifier within two months of the call.

The monitoring plan is verified by the verifier before the start of the monitoring period and is recorded by the verifier in the FuelEU database maintained by the European Commission.

3.2.5 Fines

The GHG intensity provisions stipulate that if the GHG intensity of the fuel actually used exceeds the upper limit of GHG intensity for the year, a fine calculated according to the type and amount of fuel used shall be paid. The outline of the formula for calculating the fine for each ship is as follows.

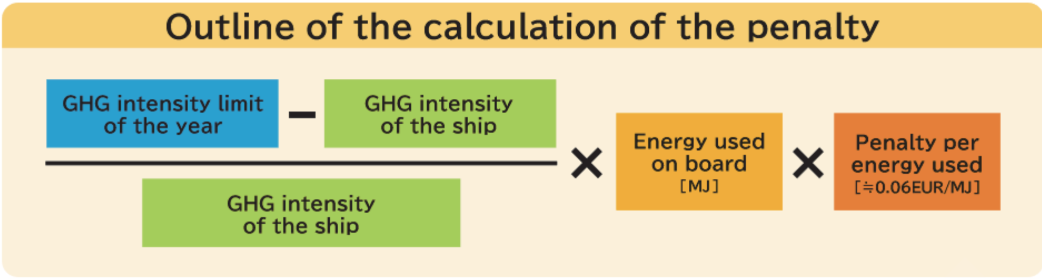

Fig. 3 Outline of the calculation of the penalty

When the result of the above formula is negative, a fine is incurred, and the absolute value is the amount of the fine. When more than one fuel is used, the “GHG intensity of the fuel actually used” in this formula is the weighted average of the amount of energy used and the GHG intensity of the ship.

The fine for a ship that fails to achieve the upper limit of GHG intensity more than twice (2 years) in consecutive monitoring periods is increased to 1+ (n‐1)/10, depending on the number of monitoring periods n for which the fine is applied. In other words, if the same ship is subject to payment of the fine for 2 consecutive years, the amount paid in the second year is 1.1 times the amount calculated by the above formula.

3.2.6 ClassNK MRV Portal Support

In order to support the EU-MRV and IMO DCS regulations, the Society provides the ClassNK MRV Portal data collection management and authentication system. This is a “one-stop” system that allows users to provide templates for data collection, report data from ships, manage data on land, apply for certification of annual reports, issue certificates of compliance, and manage invoices.

The ClassNK MRV Portal will also be updated for FuelEU Maritime so that verification of FuelEU monitoring plans and FuelEU reports can be carried out smoothly.

4. CONCLUSION

In recent years, the urgent need for global efforts to combat climate change due to frequent extreme weather events and large-scale disasters has become increasingly apparent. In international shipping, regulations and systems to reduce GHG emissions from ships are being discussed in organizations such as the IMO and the EU.

The IMO, which is responsible for developing global regulations in the maritime sector, revised its GHG reduction strategy at MEPC 80 in 2023 and set ambitious targets towards achieving net-zero GHG emissions by 2050. A new target related to the uptake of zero or near-zero GHG emission technologies, fuels, and/or energy sources was also introduced. In the future, the IMO will engage in discussions on midterm measures to achieve these targets.

On the other hand, the EU has decided to introduce regional regulations that include economic measures such as the EU-ETS system and the FuelEU Maritime regulation. These regulations are expected to increase costs for ships sailing to or from EU ports, depending on their emissions and the types of fuels used.

To advance GHG emissions reduction in international shipping, it is not only crucial to transition from conventional ships using fossil fuel to zero/low-emission ships, but also to ensure a stable supply of zero/low-emission fuels. Collaborative efforts are urgently needed among international organizations, member states, the maritime industry, the energy sector, cargo owners, the financial industry, and others. ClassNK will continue to disseminate information on regulatory developments and their impacts related to GHG reduction, and will also actively support stakeholders in their GHG reduction efforts by providing new services tailored to the needs of customers and society in addition to the currently-available “ClassNK Zero Emission Support Service”.

REFERENCES

1) Resolution MEPC.376(80), Guidelines on lifecycle GHG intensity of marine fuels (LCA guidelines)
2) Resolution MEPC.377(80), 2023 IMO Strategy on Reduction of GHG Emissions from Ships (2023 IMO GHG Strategy)

3) MEPC.1/Circ.905, Interim guidance on the use of biofuels under regulations 26, 27, and 28 of MARPOL Annex VI (DCS and CII)
4) Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system (Text with EEA relevance)
5) Regulation (EU) 2023/957 of the European Parliament and of the Council of 10 May 2023 amending Regulation (EU) 2015/757 in order to provide for the inclusion of maritime transport activities in the EU Emissions Trading System and for the monitoring, reporting and verification of emissions of additional greenhouse gases and emissions from additional ship types (Text with EEA relevance)
6) Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC (Text with EEA relevance)

Safety Requirements for Construction and Equipment of Ships Using Methanol as Fuel

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1. INTRODUCTION

In the international shipping sector, stricter regulations for prevention of air pollution and global warming have been applied in the recent years. In line with these trends, active study of the use of environment-friendly alternative fuels in place of fossil fuels is underway. In particular, development of LNG, LPG and methyl/ethyl alcohol as alternative fuels as a next-generation fuel for ships is progressing, and substantial reductions in SOx emissions are possible if they are used as fuels, as they do not contain sulfur. Moreover, reductions in CO_2 emissions are also expected. Achievement of net zero GHG emissions over the life-cycle of fuels by utilizing green methanol such as biomethanol derived from sustainable biomass or e-methanol produced using renewable energy, *etc.* is also being studied.

On the other hand, in order to use methanol as a fuel for ships, it is necessary to consider its safety. In comparison with conventional fuels, the properties of methanol include a wide combustion range, small minimum ignition energy (low flashpoint), toxicity to the human body and difficulty in confirming a flame when it ignites. The safety of methanol fuel must be verified for these factors.

Under the SOLAS Convention, Chapter II-1, Regulations 56 and 57, ships using methanol as fuel must satisfy the “International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels” (hereinafter, “the IGF Code”). However, the IGF Code does not describe the concrete safety requirements when using methanol as a fuel. Requirements are currently limited to MSC.1/Circ. 1621 “INTERIM GUIDELINE FOR THE SAFETY OF SHIPS USING METHYL/ETHYL ALCOHOL AS FUEL” issued by the IMO, and mandatory safety requirements have not been specified by international conventions, *etc*.

To contribute to the development of safety requirements for the construction and equipment of ships using methyl alcohol (methanol) as fuel, ClassNK (hereinafter, “the Society”) summarized the requirements for ensuring the safety of ships that use methanol as a fuel in Part A of the “Guidelines for Ships Using Alternative Fuels”.

This paper presents an overview of the guidelines for safety requirements for the construction and equipment of ships using methanol as a fuel, together with a commentary on the points that require attention when designing methanol-fueled ships.

2. GUIDELINES FOR SHIPS USING ALTERNATIVE FUELS, PART A

2.1 Overview

In August 2021, the Society issued Guidelines for Ships Using Alternative Fuels, Part A “Guidelines for Ships using Methyl/Ethyl Alcohol as Fuel”. Subsequently, the content of the IMO’s Interim Guideline, MSC.1/Circ. 1621 was incorporated in September 2021, and the Society released a partially-revised version of Part A as part of Guidelines for Ships Using Alternative Fuels (Edition 2.0) (hereinafter, “the Guidelines”) in June 2022.

2.2 Main Requirements of the Guidelines

2.2.1 Structure of the Guidelines

The Guidelines specify the safety-related requirements in case methanol is used as a fuel. Functional requirements are provided in Chapter 3, general requirements including risk assessment are provided in Chapter 4 and specific requirements for ships using methanol as a fuel are provided in Chapter 5 and thereafter.

2.2.2 Functional Requirements (Chapter 3)

Chapter 3 of the Guidelines specifies the functional requirements for the purpose of safe and environment-friendly design, construction and operation of propulsion machinery, auxiliary power generation machinery and/or other purpose machinery utilizing methanol.

The prescriptive requirements of these Guidelines are determined based on the totality of these functional requirements. Even in cases where a design deviates from the prescriptive requirements stipulated in the Guidelines, the design must be consistent with the functional requirements.

2.2.3 General Requirements (Chapter 4)

A risk assessment must be performed to verify the risks arising from the use of methanol fuel to persons on board, the environment, the structural strength or the integrity of the ship. Unlike LNG-fueled ships, the target scope of the risk assessment is not limited; that is, all potential hazards originating from methanol fuel must be studied. This is expected to make it possible to cope with dangers that cannot be addressed by the prescriptive requirements provided in the Guidelines.

In addition to this risk assessment, it should be noted that there may be cases in which demonstration of safety equivalence may be required as a deviation from the IGF Code, depending on the ship's flag country.

2.2.4 Ship Design and Arrangement (Chapter 5)

a) Tank arrangement

Methanol fuel tanks (hereinafter, "fuel tanks") can be integral fuel tanks or independent fuel tanks. To avoid the effects of heat due to external fire and prevent leakage of toxic, flammable methanol into other parts of the ship, integrated fuel tanks are to be surrounded by a protective cofferdam. However, installation of a protective cofferdam is not required for fuel tanks on surfaces bound by shell plating below the lowest possible waterline or other fuel tanks containing methanol, or surfaces that form the boundary with the fuel preparation space. Independent fuel tanks installed in the fuel storage hold space or on the open deck are acceptable.

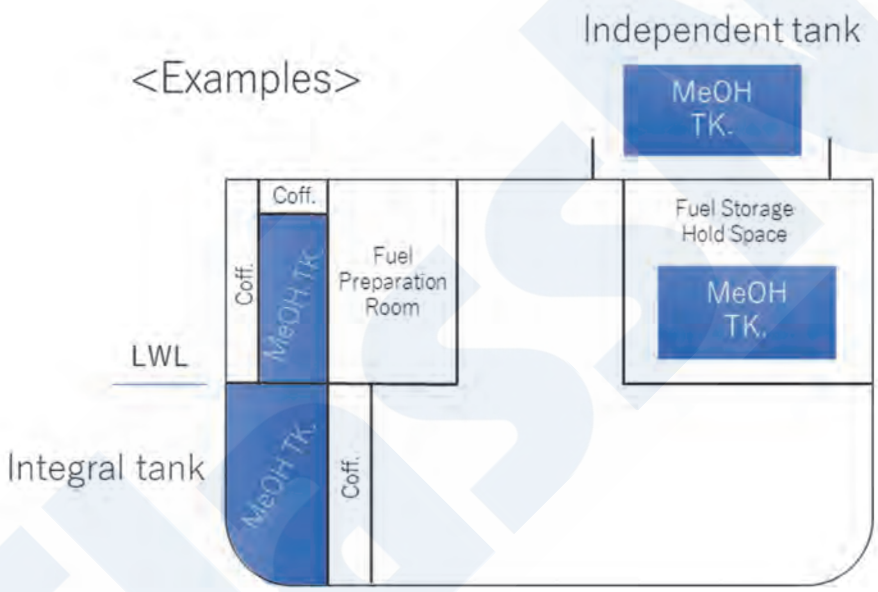

Fig. 1 Examples of arrangements of methanol fuel tanks

In case cargo-and-fuel tanks are installed in the cargo area of a chemical tanker, safety is considered to be guaranteed by the concept of the IBC Code, and the above-mentioned requirements notwithstanding, this is treated as a case in which a protective cofferdam around cargo-and-fuel tanks is not required.

To reduce the risk of damage due to collision, the fuel containment system is required to be arranged abaft of the collision bulkhead and forward of the aft peak bulkhead. This requirement is also applicable to fuel tanks on the open deck. Unlike the IGF Code, which is applicable to LNG-fueled ships, study of the fuel tank arrangement by probabilistic methods is not permissible.

b) Access to enclosed spaces containing fuel-related equipment

Direct access from non-hazardous areas to hazardous areas related to methanol fuel as provided in these Guidelines should not be permitted. In cases where such an opening is necessary for operational reasons, access by providing an airlock is permissible. However, as stipulated in Chapter 12, areas that are protected by an airlock during normal operation can be regarded as non-hazardous areas, but the equipment to be used in case the pressure differential between the protected area and the hazardous area is lost must be certified or demonstrated as suitable for use in hazardous area zone 1. Therefore, care is necessary in case of arrangements that provide direct access to the engine room from a hazardous area, even if an airlock is installed between those areas, because the equipment used in the engine room in case the pressure differential is lost is required to be an explosion-proof type suitable for hazardous area zone 1.

c) Leakage countermeasures

Drip trays are to be fitted in places where fuel leakage may occur, in particular, in way of single wall pipe connections. The capacity of drip trays must be sufficient to ensure that the maximum amount of spill according to the risk assessment can be handled. Means to safely drain or transfer methanol that has leaked into a drip tray to a dedicated holding tank are to be provided. In addition to collecting the leakage from drip trays, holding tanks must be able to collect the drain or possible leakage of methanol fuel from fuel pumps, valves and the inner pipe of double walled pipes installed in enclosed spaces. If methanol fuel is collected in holding tanks in normal operation, the Society basically thinks that it is necessary to apply the same conditions as those for fuel tanks to the holding tanks, and therefore does not accept installation in the engine room.

2.2.5 Fuel Containment System (Chapter 6)

The provisions of the Guidelines related to fuel containment systems partially incorporate the provisions of the IBC Code applied to chemical tankers that store and transport methanol as a cargo. Fuel tanks are to be fitted with a controlled tank venting system, pressure and vacuum relief valves are to be fitted on each fuel tank, and the vent outlet is to be fitted with a flame arrestor. Fuel tanks are required to be inerted with an inert gas at all times under the normal operation condition. Therefore, it should be noted that installation of the open air pipes fitted on ordinary fuel oil tanks is not acceptable.

To avoid exposure of the crew to methanol vapor, fuel tank vent outlets must be situated not less than 3 m above the deck, or not less than 3 m from the gangway if the vent outlet is located within 4 m from a gangway. Vent outlets are to be arranged at a distance of at least 10 m from the nearest air intake or opening to accommodation spaces and service spaces (living and working spaces) and ignition sources. Care is necessary in case of bulk carriers, *etc*., in which the fuel tanks and accommodation spaces tend to be located in close proximity to each other.

The availability (capacity) of inert gas to be used on a ship is to be decided taking into account the amount of inert gas necessary to achieve at least one voyage, considering the maximum expected fuel consumption and the length of the voyage, and the amount of inert gas necessary to keep the fuel tanks inerted for 2 weeks with minimum fuel consumption while in harbour. The Guidelines permit the use of an inert gas production plant and/or storage facilities to achieve this inert gas availability. In actuality, it appears that many shipbuilders and operators plan to providing onboard nitrogen generators.

2.2.6 Materials and General Pipe Design (Chapter 7)

The corrosiveness of the fuel is to be considered when selecting materials. In general, it appears that many plans use austenitic stainless steel as the material for fuel pipes and austenitic stainless steel or painted ordinary rolled steel for hull use as the material for fuel tanks. Because the methanol which is generally used as fuel contains additives and impurities, the Society also wishes to verify the methanol compatibility of the materials selected with the material or paint manufacturer from this perspective.

In determining the necessity of class materials in methanol fuel pipes, the items in connection with fuel oil in Table D 12.1 Classes of Pipes in the Society’s Rules for the Survey and Construction of Steel Ships (hereinafter, “the Rules”), Part D apply mutatis mutandis, and pipes are treated according to the classification of pipes by design pressure and design temperature. In accordance with the Rules, Part D 12.1.4-2(1), materials for pipes classified as Group I or Group II are required to conform to the Rules, Part K. Those classified as Group III may also be used according to Part D 12.1.4-2(2), provided they comply with a standard which is recognized as appropriate by the Society. For items related to the outer pipes of double walled fuel pipes, reference is to be made to the items for air as the type of medium in the Part D, Table D 12.1. Reference is to be made to the applicable provisions, corresponding to the grade of the pipe.

The inner piping of double walled pipes is to be full penetration butt welded and subjected to full radiographic testing. Flange connections are only permitted within the tank connection space, fuel preparation space or similar. However, use of flange connections is permitted in the outer piping of double walled pipes.

2.2.7 Bunkering Station (Chapter 8)

a) Prevention of vapour accumulation

The bunkering station is to be located on the open deck so that sufficient natural ventilation is provided. In case a bunkering station is to be installed in a closed or semi-enclosed space, in addition to providing mechanical ventilation, *etc*., its safety is to be verified by a risk assessment.

b) Prevention of hose breakage

To prevent breakage of bunkering hoses due to excessive loads, the connections at the bunkering station are to be of a dry-disconnect type (which does not allow fuel to spill in case of separation) equipped with a dry break-away coupling or self-sealing quick release function.

c) Bunkering lines

Bunkering lines are to be capable of inerting and gas freeing, and unless otherwise approved, bunkering lines must be in a gas-free condition when not being used in bunkering.

In chemical tankers equipped with cargo-and-fuel tanks, application of Chapter 8 of the Guidelines is not compulsory in cases where the cargo manifold and the bunkering manifold are used in common. In treating this case, the provisions of the Chapter 8 when the bunkering manifold is independent are applied. Furthermore, even in cases where the cargo manifold and bunkering manifold are used in common, the line used to load the cargo-and-fuel tanks is to be separated from other cargo lines by a removable spool piece or similar.

d) Mitigation of effects of methanol exposure

To mitigate the effects of exposure of personnel to methanol, emergency decontamination showers and eyewash stations must be arranged in close proximity to areas where there is a possibility of contact with fuel. It must be possible to use these facilities under all ambient conditions.

2.2.8 Fuel Supply to Consumers (Chapter 9)

In the basic design concept for methanol fuel, consideration is to be given to preventing of fuel leaks that expose the persons onboard, the environment or the ship to danger. Redundancy must be secured by arranging the propulsion, electric power and fuel supply systems in such a way that a single failure of fuel supply will not lead to an unacceptable loss of power.

Leakage is to be considered in fuel lines that pass through enclosed spaces in the ship. In surrounding spaces, such fuel lines are to be arranged inside a gas-tight and liquid-tight pipe or duct, and the annular space between the fuel pipe and the outer pipe or duct must be ventilated by mechanical underpressure ventilation with a capacity of at least 30 air changes per hour.

Regarding the dimensions of the outer pipe of double walled fuel pipes, the design pressure is not to be less than the working pressure of the inner pipe. In determining the dimensions of ducts, it is possible to use the calculated value of the maximum pressure in the duct in case the inner pipe ruptures. Because the current ship class rules do not provide calculation formulae for specifying the maximum pressure in ducts, appropriate formulae, analytical software, *etc*. may be selected and used.

The drain of double walled pipes in the engine room is to be led to a holding tank. As an alternative, when a drainage cock or similar is provided at the lowest part of the double walled pipe, connection to a portable drain tank and manual drain discharge by the crew is also permissible when leakage is detected. In this case, the portable drain tank containing the leaked fuel is to be stored in an area deemed to be appropriate in terms of safety, or the content of the portable tank is to be transferred to a holding tank. Portable drain tanks are not subject to the requirements for portable fuel tanks.

Installation of an automatically-operated master fuel valve may be mentioned as one requirement for the main engine fuel supply lines to individual fuel consumer or sets of consumers. These valves are to be situated in piping outside of the machinery space containing the fuel consuming equipment. Valves related to the safety function of the fuel supply equipment are required to be a fail-safe type that will operate prioritizing safety, even if power for valve operation is lost.

2.2.9 Use of Fuel (Chapter 10, Power Generation Including Propulsion and Other Energy Converters)

Chapter 10 of the Guidelines specifies the provisions for the use of dual-fuel engines and methanol single fuel engines as engines using methanol. In case use of methanol with other types of equipment is planned, it should be noted that those applications must also conform to the goal and functional requirements of Chapter 10.

2.2.10 Fire Safety (Chapter 11)

a) Containment of fire

In principle, the requirements for fire protection construction follow Chapter 9 of the Rules, Part R However, this chapter provides additional requirements for spaces that are specific to ships using methanol as a fuel. For example, since the fuel preparation spaces of methanol-fueled ships are regarded as category A for fire protection purposes, appropriate fire protection integrity is required at the boundaries with adjoining spaces. As for the fact that fuel preparation spaces are regarded as category A, this classification is only applied when studying fire protection construction. It is not necessary to regard fuel preparation spaces as category A machinery areas when providing the “means of escape” in SOLAS II, Chapter 2, Regulation 13. In this case, the same escape requirements as those for other machinery spaces can be applied.

b) Firefighting equipment

A fixed fire detection system and fire alarm system complying with the FSS Code is to be provided in all compartments containing the methanol fuel system. Based on the characteristics of methanol fires, devices which are capable of detecting methanol fires, such as heat-detection devices, *etc*. are required in addition to smoke detectors.

The representative requirements in cases where fuel tanks are located on the open deck and under the open deck are explained below.

1) On the open deck

Where fuel tanks are installed on the open deck, a fixed water spray system covering the exposed parts of the fuel tank is to be provided to dilute fuel which is accidentally spilled, cool the fuel tank and prevent fire. A fixed alcohol-resistant foam type extinguisher is also to be provided, assuming alcohol fires.

Any boundary of accommodation spaces up to the navigation bridge windows, service spaces, control stations, machinery spaces and escape routes facing fuel tanks on the open deck is to be provided with A-60 class heat insulation.

2) Under the open deck

To prevent heating of fuel tanks, fuel tank boundaries are to be separated from category-A machinery spaces and other spaces with a high risk of fire by a cofferdam of a least 600 mm, with heat insulation of not less than A-60 class.

2.2.11 Explosion Prevention and Area Classification (Chapter 12)

Certified safe type electrical equipment is to be used in hazardous areas. For use with methanol, explosion-proof electrical equipment with an explosion-proof grade of IIAT1 or higher is to be selected. In accordance with the Guidelines, Chapter 12.5, hazardous areas are classified as hazardous area zone 0, 1 or 2. In case application of the definitions in the hazardous area classification provided in Chapter 12 is to be deemed inappropriate, classification following IEC60079-10-1:2015 may be applied with special consideration of the Society.

2.2.12 Ventilation (Chapter 13)

a) Installation of ventilation systems

To avoid enlargement of the range of hazardous areas, all ducts used in ventilation of hazardous areas must be independent from ducts used in non-hazardous areas. Air inlets for hazardous enclosed spaces must be installed in areas that would be considered non-hazardous in the absence of that inlet.

An effective extraction type mechanical forced ventilation system must be installed in fuel preparation spaces and in ducts and double walled pipes including fuel piping, and must have a ventilation capacity of at least 30 air changes per hour. The ventilation inlets of double walled and duct ventilation systems are to be located in a non-hazardous area, in the open air, away from ignition sources. The inlet openings are to be protected from the ingress of water, and must be fitted with a suitable wire mesh guard.

b) Redundancy of ventilation fans

The number and power (output) of ventilation fans for fuel preparation spaces is to be such that the total ventilation fan capacity is not reduced by more than 50% if a fan with a separate circuit (power supply) from the main switchboard or emergency switchboard, or a group of fans with a common circuit becomes inoperable. In order to minimize the assumed risk, a ventilation fan configuration with redundancy is to be used, even in coastal ships in which the requirements for main switchboard busbar splitting and installation of emergency switchboards are relaxed considering route restrictions, *etc*.

2.2.13 Electrical Installations (Chapter 14)

In electrical installations, attention is to be paid to minimize the risk of ignition in the presence of a flammable atmosphere. The relevant provisions of the Rules, Part H concerning the selection of electrical equipment, laying of cables, *etc*. are to be observed.

2.2.14 Control, Monitoring and Safety Systems (Chapter 15)

a) Safety systems

The fuel safety system plays the role of preventing the spread of damage by cutting off the supply of methanol fuel by executing an automatic shutdown of corresponding tank valves, master fuel valves and bunkering valves when a fuel leak, *etc*. occurs.

As safety devices for fuel tanks, tanks are to be fitted with closed level gauging devices, arranged to ensure that a level reading is always obtainable. Two level gauges are to be installed so as to avoid opening the tank for gauge maintenance work while the fuel tank is in service. The purpose of this measure is to avoid the release of fuel outside the tank and exposure of personnel during maintenance work. However, where it is possible to carry out the necessary maintenance work while the tank is in service without releasing fuel, installation of redundant gauges may be omitted. Here, “necessary maintenance work” is considered to indicate all types of maintenance work carried out in case of a level gauge malfunction. In addition, fuel tanks should also be fitted with a visual and audible high level alarm. This device can be common with the level gauging system, but it is to be independent of the high-high level alarm.

b) Gas detection

As a means of detecting leaked methanol vapour, installation of gas detectors is required. The gas detectors required in this chapter are to be installed in order to detect the formation of a flammable atmosphere and formation of a toxic atmosphere by methanol vapour. However, the following describes the recommendations of the Society for detection of toxic atmospheres, as this is not described concretely in the guideline.

The recommended alarm setting for fixed gas detectors is TLV-TWA: 200 ppm, which is the allowable concentration in the working environment for 40 hours/week of work, assuming 8 hours/day. This is not mandatory if there is a rational reason, such as the unavailability of a fixed gas detector that can be set to an alarm setting point of 200 ppm. Since fixed type gas detectors are considered to be mainly devices which are installed to respond to leaks before damage reaches a fatal stage (e.g., fire, explosion, irrecoverable human injury or death, *etc*.), one proposal under consideration is setting the alarm at IDLH (Immediate Danger to Life and Health): 6000 ppm, this being the escape limit concentration, i.e., the limit concentration at which it is possible to avoid a condition in which escape becomes impossible or irrecoverable health damage occurs within 30 minutes.

Because Chapter 17 of the Guidelines recommends the use of portable gas detectors, portable gas detectors are also considered necessary in addition to fixed gas detectors. Since the main role of portable gas detectors is to confirm that the working environment is appropriate, the recommended setting is TLV-TWA: 200 ppm.

As actions to prevent misoperation, such as crew members entering a fuel preparation space without carrying a portable gas detector, *etc*., installation of caution plates or labels and addition of notes to the manual required in Chapter 17.2 of the Guidelines may be necessary, depending on the circumstances.

c) Liquid leak detection

Liquid leak detectors are required as safety devices for the protective cofferdams surrounding fuel tanks, ducts installed around fuel piping, fuel preparation spaces and enclosed areas where single wall fuel piping and fuel equipment are installed. Since detection of the liquid itself is considered necessary in these leak detectors, it is not permissible to install gas detectors which can only detect vapour.

3. FUTURE TRENDS

3.1 Trends in the IMO

As mentioned in the Introduction, at present, the requirements for methanol-fueled ships are limited to the release of an IMO Interim Guideline as MSC.1/Circ.1621. Rules with compelling force have not been issued at this time.

As international discussions toward the establishment of requirements for ships using methanol as fuel, in the IMO, the 8th Session of the Sub-Committee on Carriage of Cargos and Containers (CCC8) in 2022 announced a schedule for discussions on developing mandatory requirements for methanol-fueled ships (UPDATED WORK PLAN FOR THE DEVELOPMENT OF THE IGF CODE AND SAFETY PROVISIONS ON ALTERNATIVE FUELS (CCC8/18 Annex 2)), as follows.

CCC9 (2023): If time permits, start to discuss the development of mandatory requirements for methyl/ethyl alcohol.

CCC10 (2024): Proceed with the development of mandatory requirements for methyl/ethyl alcohol.

CCC11 (2025): Finalize the mandatory requirements for methyl/ethyl alcohol.

3.2 Future Response of the Society

In 2022, the Society revised and released guidelines summarizing requirements based on MSC.1/Circ.1621 as Guidelines for Ships Using Alternative Fuels, Part A (Edition 2.0) to facilitate safety assessments in the development of fuels using methanol and provide convenience to the related parties.

In the future, it is thought that the requirements of the existing MSC.1/Circ.1621 Guidelines will be reviewed again in discussions on mandatory requirements for methanol-fueled ships in the IMO. In those discussions, the Society intends to contribute to the development of more rational requirements for methanol-fueled ships, making good use of the knowledge developed with the related parties to date.

EEDI/EEXI Verification of Wind-Assisted Propulsion Systems

Ryuji MIYAKE*

1. INTRODUCTION

International shipping is responsible for international transportation and has complicated relationships among ship registry countries, real owners, operators, shippers, *etc*. Therefore, measures to reduce greenhouse gas (GHG) from international shipping do not fit into the framework of national reduction measures under the UNFCCC. As a result, the measures have been left to International Maritime Organization (IMO). On the other hand, GHG emissions from coastal (domestic) shipping are counted in the national emissions under the UNFCCC framework, and measures are being studied by the respective countries.

As part of efforts to reduce GHG emissions, IMO has focused on improvement of the energy efficiency of individual ships from the viewpoint of satisfying both GHG reduction and economic development. Since 2013, IMO has implemented EEDI (Energy Efficiency Design Index) as a fuel consumption regulation for ship design and SEEMP (Ship Energy Efficiency Management Plan) as a fuel consumption regulation for ship operation. Furthermore, IMO adopted Initial IMO GHG Strategy to reduce the GHG emissions from international shipping in 2018. As short-term measures of the GHG Strategy, EEXI (Energy Efficiency Existing Ship Index) and CII (Carbon Intensity Indicator) rating have been also begun since 2023. At MEPC 80 held in July 2023, the GHG Strategy was revised and set an enhanced common ambition to reach net-zero GHG emissions from international shipping by or around, i.e. close to 2050.

As one of elemental technologies to achieve this, the use of wind power as assisted propulsion has attracted renewed interest. In addition to the traditional sails used since antiquity, systems that use large-scale kite connected to ships to capture wind and tow the ship, rotor systems that rotate cylindrical devices mounted on the deck and generate lift force by the Magnus effect, *etc*. have already been put into practical use, and Wind-Assisted Propulsion Systems (WAPS) are progressing daily. In this paper, methods for reflecting and verifying WAPS in the EEDI/EEXI schemes are explained in detail, together with an overview of the EEDI/EEXI regulations, the history of development of IMO-related guidance, the effect of shipping routes on EEDI/EEXI, incentive programs for installation of WAPS and future issues.

2. REPRESENTATIVE WIND-ASSISTED PROPULSION SYSTEMS

IMO has newly adopted the ambitious goal of "reaching net-zero GHG emissions by or around, i.e. close 2050". As a result, there is renewed interest in technologies that use wind power as assisted propulsion as one of the elemental technologies to achieve this goal. Fig. 1 shows representative WAPS. Hard sails are hard wing sails made of FRP or other suitable materials. Due to their wing shape, they are superior to conventional soft sails used in yachts in terms of efficiency in converting wind to thrust. Soft sails can generate the same thrust as hard sails because the soft sail is unfurled along their wing-shaped frames. Towing kite takes advantage of the fact that wind speed increases at higher altitudes and is considered to have a GHG reduction effect of 20% or more since the kite can capture wind at higher altitudes. Although the towing kite has problems with deployment and recovery for the operation, systems are now designed to perform deployment and recovery automatically using the bow mast, and large towing force can be obtained because kite turn in a figure 8 motions and move at high speed acting as a wing. In rotor sail systems, cylindrical rotors are vertically mounted on the ship’s deck and generate lift force by the Magnus effect when they capture wind. The principle is the same as that of a curveball in baseball, which curves due to the rotation of the ball. The suction wing has a suction slit in a steel sail with an elliptical horizontal cross section and is capable of generating large lift force using the air suction effect to increase airflow adhesion. In the hull form concept, the ship’s hull itself is wing-shaped, so it is possible to convert wind energy to propulsion power even without additional equipment. Propulsion power is maximized using the principle that the wing-shaped hull generates lift force, mainly in the form of leading-edge thrust, when oblique wind strikes the hull above the waterline.

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3. HISTORY OF DEVELOPMENT OF GUIDANCE ON INNOVATIVE ENERGY EFFICIENCY TECHNOLOGIES

https://www.mol.co.jp https://www.neoline.eu https://www.kline.co.jp

(a) Hard Sail (b) Soft Sail (c) Towing Kite

https://www.norsepower.com http://site.craintechnologies.com https://ladeas.no

(d) Rotor Sail (e) Suction Wing (f) Hull Form

Fig. 1 Representative Wind-Assisted Propulsion Systems

At MEPC 65 held in 2013, "GUIDANCE ON TREATMENT OF INNOVATIVE ENERGY EFFICIENCY TECHNOLOGIES FOR CALCULATION AND VERIFICATION OF THE ATTAINED EEDI" [1] was approved to incorporate the effects obtained from innovative energy efficiency technologies such as WAPS, Hull Air Lubrication Systems, Waste Heat Recovery Systems and other innovative energy efficiency technologies into the EEDI framework. However, it was not possible to reflect the effects of WAPS in EEDI because the "probability of occurrence for the respective wind speed and angle encountered in the main global shipping routes" as well as the estimation and verification methods of "wind-assisted propulsion force for the respective wind speed and angle" specified in this guidance were not yet completed. On the other hand, there were several concrete projects to introduce WAPS in Japan, and industry demanded the early development of an environment in which their fuel consumption performance can be officially evaluated. In order to reflect the effects of WAPS in EEDI as quickly as possible, Japan, together with China and Germany, submitted a draft amendment to "GUIDANCE ON TREATMENT OF INNOVATIVE ENERGY EFFICIENCY TECHNOLOGIES" related to WAPS at MEPC 76 held in March 2021 [2]. Although Finland, France, Comoros and RINA also submitted proposals for WAPS at MEPC 76, these proposals were deferred to the next MEPC 77 due to time constraints. At MEPC 77 held in November 2021, a draft amendment [3] based on the proposal by Japan, China and Germany at MEPC 76, which also reflected elements of the proposals by Finland, France, Comoros and RINA was approved. As a result, IMO issued "2021 GUIDANCE ON TREATMENT OF INNOVATIVE ENERGY EFFICIENCY TECHNOLOGIES FOR CALCULATION AND VERIFICATION OF THE ATTAINED EEDI AND EEXI" (hereinafter, "GUIDANCE ON INNOVATIVE ENERGY EFFICIENCY TECHNOLOGIES") [4], and the effects of WAPS technologies could at last be reflected in the EEDI/EEXI schemes.

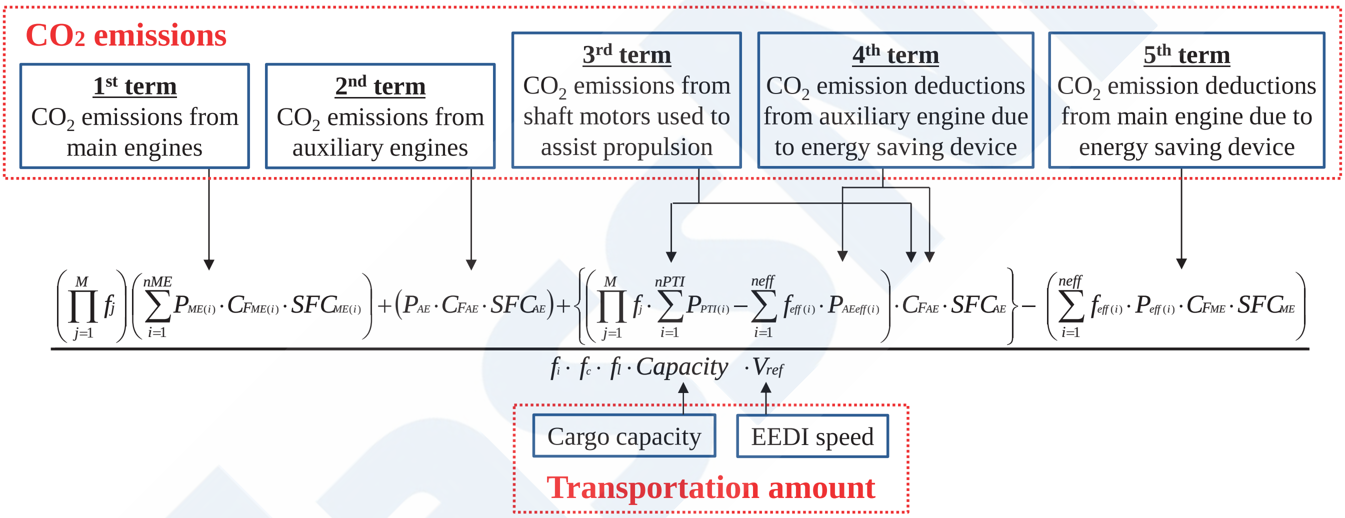
4. OVERVIEW OF EEDI/EEXI REGULATIONS

EEDI and EEXI are one of specifications for newly built ships and are indexes that express "potential efficiency". As the basic concept, as shown in Eq. (1), these indexes are calculated by multiplying the certified specific fuel oil consumption (SFC), CO_2 conversion factor and engine power and dividing the product by the ship’s cargo capacity and speed. The result expresses the expected CO_2 emission (g) when a cargo of one ton is transported one nautical mile. They are applicable only to specified ship types. Ships that exceed the specified size for each type must comply with the required value ("Required EEDI/EEXI") for its type, but required values are not set for ships which is less than the specified size.

$$\text{EEDI/EEXI (g/t}\cdot\text{mile)} = \frac{CO_2 \text{ conversion factor} \times \text{SFC (g/kWh)} \times \text{Engine power (kW)}}{\text{Cargo capacity (t)} \times \text{Ship speed (mile/h)}} \quad (1)$$

4.1 EEDI/EEXI Calculation Formula

As shown in Fig. 2, at a glance, the EEDI/EEXI calculation formula appears to be complicated, but its idea is based on the fundamental concept described above. The first term in the numerator of the formula is used to estimate the CO_2 emissions from the main engines, and the CO_2 emissions are calculated by multiplying the engine power, specific fuel oil consumption (SFC) and CO_2 conversion factor. The second term is used to estimate the CO_2 emissions from the auxiliary engines, and the basic idea is the same as that of the main engines. The third term is used to estimate the CO_2 emissions from shaft motor(s) used to assist propulsion. The fourth and fifth terms are CO_2 emission deductions from the auxiliary engine and main engine emissions when an energy saving device (ESD) is installed. In this case, the CO_2 emissions from the auxiliary engine or main engine can be reduced by an amount equivalent to the energy-saving effect of the ESD. The cargo capacity in the denominator is the deadweight (DWT) at the maximum summer load draft, except for passenger ships, and the EEDI speed V_{ref} is the ship speed at the maximum summer load draft at 75% of MCR (Maximum Continuous Rating).



$$\frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)}\cdot C_{FME(i)}\cdot SFC_{ME(i)}\right)+\left(P_{AE}\cdot C_{FAE}\cdot SFC_{AE}\right)+\left\{\left(\prod_{j=1}^{M} f_j\cdot\sum_{i=1}^{nPTI}P_{PTI(i)}-\sum_{i=1}^{neff} f_{eff(i)}\cdot P_{AEeff(i)}\right)C_{FAE}\cdot SFC_{AE}\right\}-\left(\sum_{i=1}^{neff} f_{eff(i)}\cdot P_{eff(i)}\cdot C_{FME}\cdot SFC_{ME}\right)}{f_i\cdot f_c\cdot f_l\cdot Capacity\cdot V_{ref}}$$

P_{ME} :	Main engine power 0.75×(MCR_{ME} − P_{PTO}) [kW]
P_{AE} :	Auxiliary engine power 0.025×MCR_{ME}+250 [kW] (0.05×MCR_{ME}, if MCR_{ME} < 10,000 kW)
P_{PTI} :	75% of output power by shaft motor [kW]
SFC :	Specific fuel oil consumption [g/kWh]
C_F :	CO_2 conversion factor corresponding to fuel type
Capacity :	DWT (70% DWT for container ships and GT for passenger ships)
V_{ref} :	Ship speed at P_{ME} at maximum summer load draft (draft at 70% DWT for container ships) in calm seas [knots]

Fig. 2 EEDI/EEXI calculation formula

4.2 Method for Reflecting Energy Efficiency Technologies in EEDI/EEXI

As shown in Table 1, "innovative energy efficiency technologies" are classified into three categories in EEDI/EEXI. The first is Category A and includes technologies that affect propulsion efficiency and total resistance, as reflected in the speed-power curve. Additional devices such as ducts and fins installed on the stern and improvement of the hull form fall under this category. As shown in Fig. 3, the effect of Category A technologies is reflected in the main engine power and the ship speed. The second is Category B technologies, which reduce main engine power by activating the device. Hull Air Lubrications Systems fall under Category B-1, while WAPS are classified as Category B-2 because the operation depends on the ambient environment. Their effects are reflected in the 5th term of the numerator. The third is Category C, which reduces the power of auxiliary engines or motors by activating the device. Waste Heat Recovery Systems are classified as Category C-1, and Photovoltaic Cells are classified as Category C-2 because their operation depends on the ambient environment. Their effects are reflected in the 4th term of the numerator. The concrete EEDI/EEXI calculation and verification methods for the Energy Saving Devices (ESD) in Category B and Category C are specified in the IMO's GUIDANCE ON INNOVATIVE ENERGY EFFICIENCY TECHNOLOGIES.

Table 1 Categories of innovative energy efficiency technologies

Category		Contents		Energy Saving Devices
Category A		Influence on propulsive efficiency and total resistance, and consequently reflected in the speed-power curve.		Stern duct, rudder bulb, Hull form optimization
Category B	(B-1)	Main engine power is reduced at any time during the operation of the system.	$f_{eff} = 1.0$	Hull Air Lubrication Systems
	(B-2)	Main engine power is reduced depending on the ambient environment.	$f_{eff} < 1.0$	Wind-Assisted Propulsion Systems
Category C	(C-1)	Auxiliary engine/motor power is reduced at any time during the operation of the system.	$f_{eff} = 1.0$	Waste Heat Recovery Systems
	(C-2)	Auxiliary engine/motor power is reduced depending on the ambient environment.	$f_{eff} < 1.0$	Photovoltaic Cells

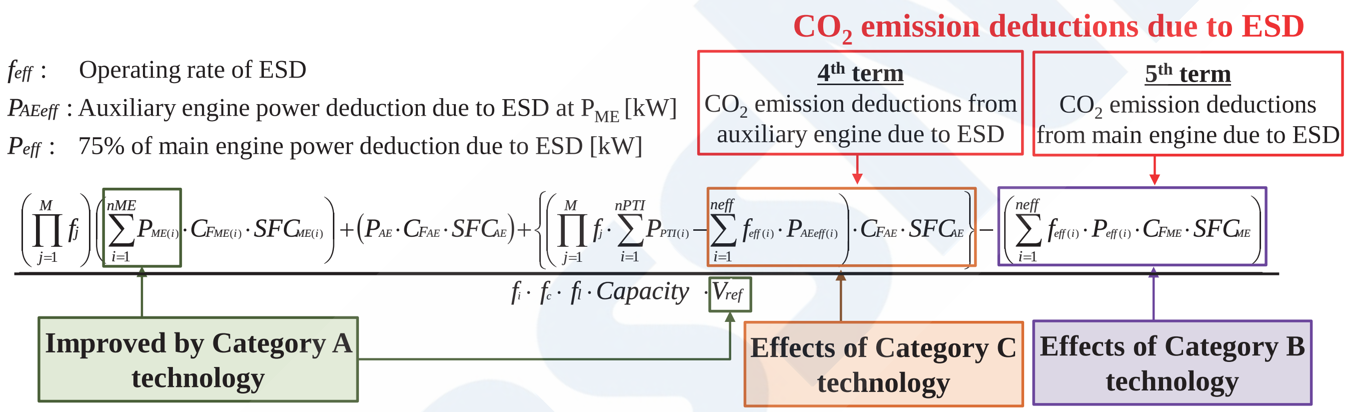


Fig. 3 Calculation method of EEDI/EEXI for each category of innovative energy efficiency technology

5. METHOD FOR REFLECTING EFFECT OF WAPS IN EEDI/EEXI

WAPS reduce main engine power, but they depend on the ambient environment. Therefore, they are classified as Category B-2, their reduction effect is reflected in the 5th term of the numerator. The concrete calculation method for WAPS is specified in the GUIDANCE ON INNOVATIVE ENERGY EFFICIENCY TECHNOLOGIES. As shown in Fig. 4, the propulsion power generated by WAPS is calculated by multiplying the Wind Force Matrix, which gives the wind-assisted propulsion force for the respective wind speed and angle, and the Global Wind Probability Matrix, which gives the probability of occurrence for the respective wind speed and angle encountered in the main global shipping routes. The reduction of propeller propulsion power is calculated by dividing the propulsion power obtained from the WAPS by the ship's propulsion efficiency, and the CO_2 emission deductions from the main engines is then calculated based on this reduction of propeller propulsion power and the electric power demand of the WAPS.

$$\frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}\right) + \left\{\left(\prod_{j=1}^{M} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) \cdot C_{FAE} \cdot SFC_{AE}\right\} - \boxed{\left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}\right)}}{f_i \cdot f_c \cdot f_l \cdot Capacity \cdot V_{ref}}$$

$$\boxed{(f_{eff} \cdot P_{eff})} = \left(\frac{1}{\sum_{k=1}^{q} W_k}\right) \cdot \left(\left(\frac{0.5144 \cdot V_{ref}}{\eta_D} \sum_{k=1}^{q} F(V_{ref})_k \cdot W_k\right) - \left(\sum_{k=1}^{q} P(V_{ref})_k \cdot W_k\right)\right)$$

with $F_1 - F_k \geq 0 \wedge F_{k-1} - F_k \geq 0$

(sorting all force matrix elements in descending order)

and $\sum_{k=1}^{q-1} W_k < \frac{1}{2} \wedge \sum_{k=1}^{q} W_k \geq \frac{1}{2}$

(defining q: the number of elements added in the formula)

$F(V_{ref})_k$: Matrix which represents the wind-assisted propulsion force for the respective wind speed and angle (Wind Force Matrix)

W_k : Matrix which represents the probability of occurrence for the respective wind speed and angle encountered in the main global shipping routes (Global Wind Probability Matrix)

$P(V_{ref})_k$: Matrix which represents electric power demand for the operation of the WAPS

Fig. 4 Method for reflecting effect of WAPS in EEDI/EEXI

5.1 Wind Force Matrix

As shown in Table 2, Wind Force Matrix represents a matrix of the wind-assisted propulsion force for the respective wind speed and angle. GUIDANCE ON INNOVATIVE ENERGY EFFICIENCY TECHNOLOGIES specifies that the Wind Force Matrix is to be obtained from wind tunnel model tests, CFD and other numerical calculations and full-scale tests, depending on the type of WAPS. For example, in the case of towing kite, numerical calculations such as CFD validated by full-scale tests can also be accepted since it is difficult to conduct the wind tunnel model tests. In any case, it is necessary to create the Wind Force Matrix by an appropriate estimation method corresponding to the type of WAPS.

Table 2 Matrix of wind-assisted propulsion force for the respective wind speed and angle (Wind Force Matrix)

Wind Angle(°) / Wind speed(m/s)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
<1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	3.7	5.0	6.0	6.5	6.7	6.6	6.2
<4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	9.3	13.3	16.6	19.1	21.0	22.1	22.6	22.6	22.0	21.0	19.6
<5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4	13.5	20.6	26.5	31.4	35.1	37.7	39.2	39.6	39.1	37.8	35.8	33.3	30.5
<6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	19.9	30.1	38.8	45.9	51.4	55.1	57.2	57.7	56.8	54.8	51.8	48.1	43.9	39.4
<7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	22.2	36.5	48.9	59.2	67.2	72.9	76.3	77.4	76.6	74.1	70.3	65.6	60.2	54.5	48.6
<8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.6	37.9	55.1	69.8	81.6	90.3	95.9	98.5	98.5	96.1	92.0	86.6	80.4	73.6	66.5	59.2
<9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	32.5	55.6	75.8	92.7	105.9	115.1	120.4	122.1	120.7	116.8	111.2	104.4	96.8	88.7	80.2	71.4
<10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.1	48.1	75.1	98.5	117.6	132.0	141.6	146.4	147.0	144.3	139.1	132.1	124.0	115.1	105.6	95.5	85.3
<11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.4	65.3	96.5	123.1	144.5	160.1	169.8	174.0	173.6	169.6	163.1	154.9	145.6	135.3	124.2	112.6	101.0
<12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	44.0	84.1	119.7	149.7	173.4	190.0	199.8	203.3	201.9	196.8	189.2	179.8	169.2	157.4	144.7	131.6	119.2
<13	0.0	0.0	0.0	0.0	0.0	0.0	9.1	58.9	104.5	144.7	178.3	204.1	221.8	231.6	234.5	232.1	225.9	217.3	206.8	194.8	181.4	167.0	152.8	140.4
<14	0.0	0.0	0.0	0.0	0.0	0.0	18.8	75.1	126.5	171.6	208.8	236.8	255.5	265.2	267.6	264.3	257.2	247.5	235.8	222.4	207.3	191.4	176.5	165.0
<15	0.0	0.0	0.0	0.0	0.0	0.0	29.4	92.6	150.2	200.3	241.1	271.5	291.1	300.8	302.6	298.5	290.5	279.8	266.9	251.9	235.1	218.0	203.1	193.3
<16	0.0	0.0	0.0	0.0	0.0	0.0	40.8	111.4	175.4	230.8	275.4	308.1	328.6	338.4	339.6	334.8	325.9	314.3	300.0	283.4	265.0	247.0	232.6	225.3
<17	0.0	0.0	0.0	0.0	0.0	0.0	53.2	131.5	202.3	263.1	311.7	346.6	368.1	377.9	378.6	373.1	363.5	350.8	335.2	316.9	297.0	278.5	265.4	261.2
<18	0.0	0.0	0.0	0.0	0.0	0.0	66.5	152.9	230.7	297.2	349.8	387.1	409.6	419.4	419.8	413.7	403.3	389.5	372.4	352.4	331.2	312.6	301.4	301.1
<19	0.0	0.0	0.0	0.0	0.0	0.0	80.8	175.6	260.8	333.1	389.8	429.5	453.0	463.0	463.0	456.3	445.2	430.3	411.7	390.0	367.7	349.4	340.6	344.8
<20	0.0	0.0	0.0	0.0	0.0	0.0	95.9	199.6	292.4	370.8	431.8	473.9	498.5	508.6	508.3	501.1	489.3	473.2	453.0	429.6	406.5	389.1	383.3	392.5
<21	0.0	0.0	0.0	0.0	0.0	0.0	111.9	224.8	325.7	410.4	475.6	520.3	546.0	556.3	555.7	548.1	535.5	518.2	496.4	471.4	447.6	431.5	429.5	444.1
<22	0.0	0.0	0.0	0.0	0.0	0.0	128.9	251.4	360.5	451.7	521.4	568.7	595.5	606.0	605.3	597.3	583.9	565.4	541.8	515.4	491.2	476.9	479.0	499.6
<23	0.0	0.0	0.0	0.0	0.0	0.0	146.8	279.3	396.9	494.7	569.1	619.0	647.0	657.8	657.0	648.6	634.4	614.6	589.4	561.5	537.3	525.2	532.0	558.8
<24	0.0	0.0	0.0	0.0	0.0	0.0	165.6	308.4	434.9	539.6	618.7	671.3	700.6	711.8	710.8	702.0	687.1	665.9	639.0	609.9	585.9	576.4	588.4	621.9
<25	0.0	0.0	0.0	0.0	0.0	19.4	185.3	338.8	474.5	586.3	670.2	725.7	756.2	767.8	766.8	757.7	741.9	719.3	690.7	660.4	636.9	630.5	648.3	688.8
≥25	0.0	0.0	0.0	0.0	0.0	23.5	195.5	354.6	494.9	610.3	696.7	753.6	784.7	796.6	795.6	786.3	770.1	746.8	717.4	686.6	663.4	658.7	679.5	723.6

5.2 Consideration of Effect of Altitude on Wind Speed

In comparison with the wind speed at higher altitudes, the wind speed near the ground or sea surface decreases due to the effect of friction, as shown in Fig. 5. There is a "power law" as an expression for the variation of wind speeds with height from the ground or sea (vertical distribution of wind speed). In the GUIDANCE ON INNOVATIVE ENERGY EFFICIENCY TECHNOLOGIES, the 1/9 power law based on the wind speed at 10m above the sea level has been adopted in accordance with the ITTC recommended procedures so that the effect of altitude on wind speed can be considered, as shown in Eq. (2).

Since towing kite flies at higher altitudes, their towing force should be obtained using the wind speed at the flight altitude. Moreover, the Wind Force Matrix for towing kite need to be created considering the vertical distribution of wind speed. The wind speed at 300m above sea is 1.46 times greater than at 10m above sea, and 100m above sea it is 1.29 times greater, as shown in Fig. 6.

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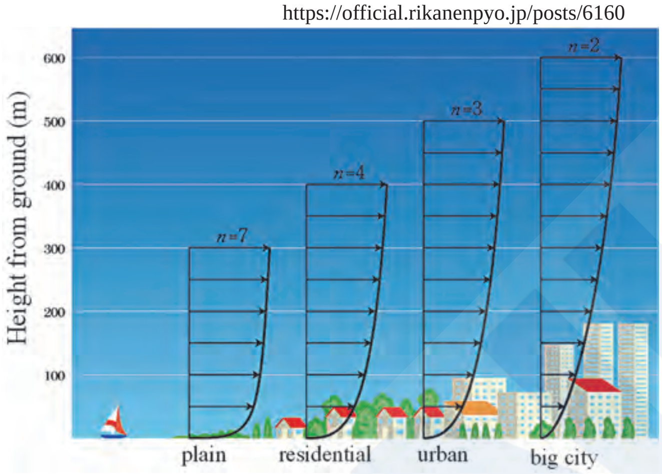


Fig. 5 Vertical distribution of wind speed

$$
\begin{aligned}
v_{Zref} &= v_{10m}\left(\frac{Z_{ref}}{10}\right)^{\alpha} \quad for \;\; z_{ref} < 300m \\
v_{Zref} &= v_{10m}\left(\frac{300}{10}\right)^{\alpha} \quad for \;\; z_{ref} \geq 300m
\end{aligned}
\tag{2}
$$

Z_{ref}: reference height above the sea level (m)
v_{10m}: wind speed at 10m above the sea level (m/s)
v_{Zref}: resulting wind speed at the reference height (m/s)
α: taken as 1/9 conforming to the ITTC recommended procedures

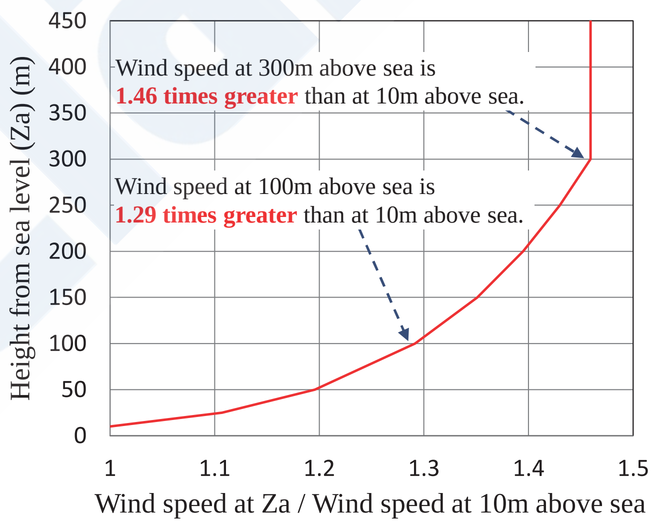
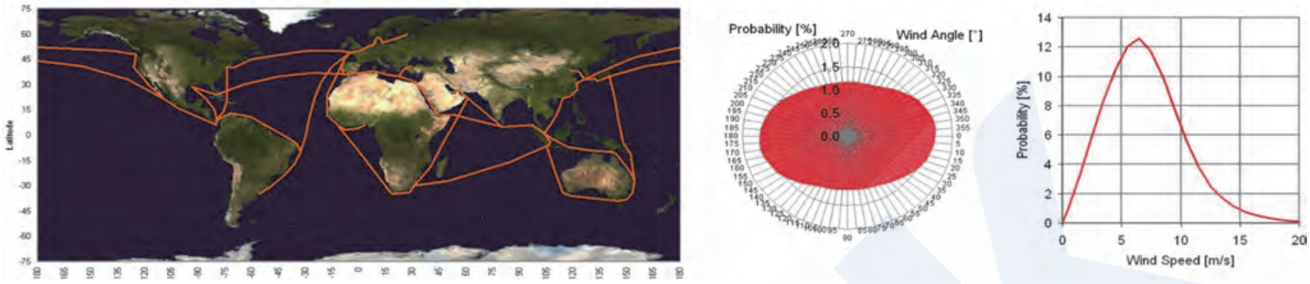


Fig. 6 Vertical distribution of wind speed above the sea level

5.3 Global Wind Probability Matrix

Since IMO develops regulations based on the assumption that a ship may operate on any shipping route in the world, ships must be evaluated for not specific shipping routes but all routes worldwide. Therefore, as shown in Fig. 7, Global Wind

Probability Matrix is defined as a matrix of the probability of occurrence for the respective wind speed and angle encountered in the main global shipping routes. Due to the route effect, there is some divergence between the effects of WAPS in the EEDI/EEXI (which are based on the global average of wind conditions) and their actual effects, but this is a limitation of the concept as a design index. Therefore, the actual effect is reflected in the Carbon Intensity Indicator (CII), which is an operational index.



Wind Speed [m/s] \ Wind Angle [°]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
<1	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
<2	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
<3	0.0009	0.0009	0.0009	0.0009	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008
<4	0.0013	0.0013	0.0013	0.0013	0.0012	0.0012	0.0012	0.0012	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0010	0.0010	0.0010	0.0010	0.0011	0.0011	0.0011	0.0011	0.0011
<5	0.0017	0.0017	0.0017	0.0016	0.0016	0.0015	0.0015	0.0015	0.0014	0.0014	0.0013	0.0013	0.0013	0.0012	0.0012	0.0012	0.0012	0.0012	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013
<6	0.0021	0.0020	0.0020	0.0019	0.0018	0.0018	0.0017	0.0016	0.0016	0.0015	0.0015	0.0014	0.0014	0.0014	0.0014	0.0013	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014	0.0015	0.0015
<7	0.0022	0.0022	0.0021	0.0020	0.0020	0.0019	0.0018	0.0017	0.0017	0.0016	0.0015	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014	0.0015	0.0015	0.0015	0.0015
<8	0.0020	0.0020	0.0020	0.0019	0.0019	0.0018	0.0017	0.0016	0.0016	0.0015	0.0014	0.0014	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0014	0.0014	0.0014
<9	0.0017	0.0017	0.0017	0.0016	0.0016	0.0016	0.0015	0.0014	0.0014	0.0013	0.0013	0.0012	0.0012	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0012	0.0012
<10	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0012	0.0012	0.0011	0.0011	0.0010	0.0010	0.0010	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0008	0.0008	0.0008	0.0009	0.0009
<11	0.0010	0.0010	0.0010	0.0010	0.0009	0.0009	0.0009	0.0009	0.0009	0.0008	0.0008	0.0008	0.0008	0.0007	0.0007	0.0007	0.0007	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
<12	0.0007	0.0007	0.0007	0.0007	0.0007	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
<13	0.0004	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002	0.0002	0.0002
<14	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
<15	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
<16	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
<17	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
<18	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<19	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<20	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<21	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<22	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<23	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<24	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<25	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
>=25	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Fig. 7 Matrix of probability of occurrence for the respective wind speed and angle encountered in the main global shipping routes (Global Wind Probability Matrix)

5.4 Effect of Shipping Route on EEDI/EEXI

According to China [5], it has been reported that the EEDI improvement effect was only 1.6% when a Wind Probability Matrix for all routes worldwide was used to evaluate the VLCC equipped with two hard sails shown in Fig. 8, but when a Wind Probability Matrix based on routes limited to the Middle East/Far East was used, the improvement in EEDI was 16%. This remarkable difference is thought to have occurred because the Middle East-Far East Routes are an ideal environment for WAPS, in that ships are frequently sailing with beam winds.

Fig. 8 VLCC equipped with two hard sails (Dalian Shipbuilding Industry Company; China)

5.5 Incentives for Installation of WAPS

Since the effect of WAPS calculated for EEDI/EEXI and the actual effect diverges due to the route effect, Germany and Finland, which were concerned about the effect on popularization of WAPS, submitted an additional draft amendment to IMO with the aim of incentivizing the installation of WAPS [6)], and as a result of deliberations, this proposal was accepted. Since it is assumed that wind-assisted ships will operate mainly on routes with favorable strong winds, the two countries proposed using only the top half of wind speeds in Global Wind Probability Matrix, and disregarding the remainder as an incentive to encourage installation of WAPS. However, this approach simply applies the idea of the 1/3 significant wave height (mean value of the highest 1/3 of waves, which are considered "significant"), and is not based on clear physical grounds. In the proposal by Germany and Finland, the countries reported that the EEDI/EEXI improvement of the 8,660 DWT RO-RO cargo ship equipped with rotor sails shown in Fig. 9 was 15% without this incentive and 30% with the incentive (this calculation used only the top half of the highest wind speeds). Although the results will differ case by case, at least in the example studied here, the EEDI/EEXI improvement effect was doubled by utilizing this incentive.

Fig. 9 8,600 DWT RO-RO cargo ship equipped with rotor sails

6. EEDI/EEXI VERIFICATION OF WAPS

EEDI/EEXI verification of WAPS is conducted in accordance with the GUIDANCE ON INNOVATIVE ENERGY EFFICIENCY TECHNOLOGIES. Various documents including the grounds for setting the Wind Force Matrix (wind tunnel test results, CFD and other numerical calculation results, full-scale test results, *etc*.) are confirmed in the preliminary verification, and the EEDI/EEXI values is finally verified by confirming the configuration and installation of the WAPS in the final verification.

7. REVIEW

Since early reflection of the effects of WAPS in EEDI was prioritized in the revision of the GUIDANCE ON INNOVATIVE ENERGY EFFICIENCY TECHNOLOGIES, there was remaining room for improvement, for example, in the validity of incentives, *etc*. Therefore, in the near future, revisions (improvements) that enable more accurate evaluation of the effects of WAPS is desired. The items that are considered to require improvement are as follows.

1) Although EEDI/EEXI is evaluated under the ship speed at 75% of MCR, slow steaming has now become the usual practice. However, as a result, the EEDI/EEXI ship speed deviates from the actual speed now. The effect of WAPS increases as the ship speed decreases, which means the actual effect of WAPS is under-estimated in EEDI/EEXI. Therefore, it is desirable to develop and adopt a formula for correcting the ship speed.
2) Since a ship may be used on any route in the world, ships are evaluated under not specific shipping routes but the main global shipping routes in the revision guidance. Although this results in a deviation between the effect of WAPS in EEDI/EEXI and the actual effect, this is a limitation of the concept of design index. Therefore, the actual effect is reflected in CII, which is an operational index. Even on the main global shipping routes, a route with the optimum wind speed and angle for WAPS exists. Therefore, it is desirable to develop and adopt a Wind Probability Matrix based on those optimum routes.
3) Accurate prediction (evaluation) of the effects of WAPS on specific shipping routes is helpful for business discussions among

manufacturers, ship owners and other related parties. Therefore, although it is not related to IMO, if Wind Probability Matrix for specific shipping routes is specified in the IMO's Guidance as reference information, it will be extremely beneficial for the related parties, and can also be used effectively in performance appraisals by third parties.

4) Since the Revised GUIDANCE has not considered the effects of oblique sailing and counter-steering caused by WAPS, it will be necessary to investigate these effects, and if necessary, develop and adopt correction formulae for their effects.
5) To incentivize the installation of WAPS, a method of considering only the top half of wind speeds in the Global Wind Probability Matrix and disregarding the remaining half has been adopted, but this is analogous to the idea of the 1/3 significant wave height (mean value of the highest 1/3 of waves), and does not have clear physical grounds. Therefore, the validity of this approach should be verified, and it should be improved if necessary.
6) It is desirable to specify the details on methods for implementation and verification of wind tunnel tests, CFD and other numerical calculations, full-scale tests and sea trials in the near future.

8. CLASS NK GUIDELINES FOR WIND-ASSISTED PROPULSION SYSTEMS

In 2019, ClassNK released "Guidelines for Wind-Assisted Propulsion Systems for Ships (First Edition)" as a guideline for the safe design of Wind-Assisted Propulsion Systems to conduct plan approval, and it became possible to understand the design elements that should be taken into account in the design of WAPS by referring to the Guidelines. The Guidelines were substantially updated in Edition 2.0 in 2023, reflecting the knowledge gained in actual projects and the results of recent research and development. In Edition 2.0, the composition of the entire Guidelines has been reviewed to enable easier understanding by both Wind-Assisted Propulsion System designers and ship designers, and has been organized into three parts: "Wind-Assisted Propulsion Systems", "Base Ships", and "Surveys", and requirements have been refined and clarified. As a result, a comprehensive check of the points that should be considered when designing and installing WAPS on ships is now possible.

Edition 2.0 specifies that the effects of WAPS can be reflected in EEDI/EEXI in accordance with the IMO's GUIDANCE ON INNOVATIVE ENERGY EFFICIENCY TECHNOLOGIES, and also states that evaluations can be conducted by other methods deemed appropriate by Society, including evaluations of the effects of WAPS on specific shipping routes.

9. CONCLUDING REMARKS

In revision (improvement) of the IMO's GUIDANCE ON INNOVATIVE ENERGY EFFICIENCY TECHNOLOGIES to enable more accurate evaluation of the effects of Wind-Assisted Propulsion Systems, ClassNK will be happy if we can contribute to the maritime industry by continuing to provide positive support in the technological aspect. We also hope that we can continue to contribute to various third-party certification activities in connection with GHG, beginning with the EEDI/EEXI verification for WAPS, and also including performance appraisals for specific shipping routes and certifications of actual GHG emission reductions.

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GHG Verification: Introduction to Supply Chain Emissions (Scope 1, 2, 3)

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1. BACKGROUND

"Climate change" refers to the phenomenon of long-term changes in the global climate. "Global warming", which is one factor in climate change, is the phenomenon of rising temperatures due to increased levels of greenhouse gases (hereinafter, GHG, abbreviation: GHG[*1]) in the atmosphere worldwide. It has been reported that global warming has a wide range of effects on the planet as a whole, including the following:

1) Temperature rise: The average temperature of the planet is rising due to increasing levels of GHG, causing extreme temperature changes and changes in weather patterns.
2) Melting of glaciers and rising sea levels: Glaciers and ice sheets are melting as a result of warming, contributing to rising sea levels.
3) Extreme weather events: Extreme weather events such as heat waves, torrential rain, typhoons, *etc*. are increasing, causing abnormal weather conditions that are impacting agricultural products and ecosystems.
4) Impacts on ecosystems: Ecosystems are changing due to warming, and decreased biodiversity and ecosystem collapse are feared.
5) Impacts on agriculture and food supplies: Global warming also affects agricultural production, and reduced harvests and destabilized food supplies may become problems.

Measurement and reporting of GHG emissions are the foundation for global warming countermeasures, and a number of international standards and guidelines have been established. Understanding these makes it possible for companies and organizations to reduce environmental loads and build the foundation for realizing a sustainable economy. This paper describes the concrete standards and guidelines, focusing on the importance of GHG verification and evaluation of emissions in supply chains.

2. INTERNATIONAL STANDARDS AND GUIDELINES FOR MEASUREMENT AND REPORTING OF GHG EMISSIONS

A number of international standards and guidelines for measurement and reporting of GHG emissions exist, including the following:

1) United Nations Framework Convention on Climate Change (UNFCCC) guidelines: Under the UNFCCC, each country is required to report its own GHG emissions. The UNFCCC provides international guidelines on measurement, reporting and verification of GHG, supporting reporting by each country based on a methodology with international consistency.
2) Greenhouse Gas Protocol (hereinafter, GHG Protocol): This is a standard for evaluating and reporting GHG emissions by companies and organizations, and defines the concepts of Scope 1, Scope 2 and Scope 3.
3) ISO 14064: This is an international standard on measurement, reporting and verification of GHG, which provides comprehensive guidelines for GHG measurement and reporting methods, data management and verification processes. ISO 14064 comprises the following parts.

① ISO 14064-1: Quantification and reporting of GHG – Provides methods for evaluation of GHG emissions by companies (organizational level).
② ISO 14064-2: Quantification and reporting of GHG – Focuses on project-based efforts, providing methods for evaluating

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*1 The revised UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention (Decision 24/CP.19, Annex) specify seven types of greenhouse gases (GHG): carbon dioxide (CO_2), methane (CH_4), dinitrogen oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

the effects of specific projects in reducing or removing GHG (project level).

③ ISO 14064-3: Quantification and reporting of GHG – Provides methods for verification and validation of GHG statements and qualification of verifiers.

4) IASE 3410: An international standard established by the Institute of Internal Auditors (IIA) which focuses mainly on GHG reports as part of assurance work for nonfinancial information by financial auditors. IASE 3410 secures the reliability of environment-related data and reports, and contributes to enhancing the transparency of information related to sustainability.

These standards and guidelines have the following important roles in evaluations of environmental impacts by countries and organizations and promotion of initiatives toward sustainability.

1) Enhancement of transparency and reliability: Measurement and reporting in accordance with these standards and guidelines ensure the transparency and reliability of the emissions data of organization and companies, and allows stakeholders to make judgments based on accurate information.
2) Possibility of comparison and evaluation: Data based on these guidelines makes it possible to compare and evaluate emissions between different organizations, companies and industries, making it possible to promote efforts to achieve sustainability and improvement of corporate performance.
3) Observance of regulations and risk management: Although regulations related to GHG emissions exist in many countries and regions, data collection and reporting in accordance with these standards and guidelines supports observance of those regulations and aids in reducing the risk of violations.
4) Sustainable management: Measurement and improvement of emissions by the reporting organization or company makes it possible to carry out initiatives to reduce environmental impacts. This contributes to long-term management strategy and improvement of brand value.
5) Response to requests by customers and consumers: With heightened concern about the environment, many customers and consumers are interested in information about sustainability. Reporting based on these standards and guidelines is one means of responding to their requests.
6) International cooperation and initiatives: Because these standards and guidelines are widely referenced internationally, they can be used as common standards by different countries and regions, facilitating international cooperation and initiatives, and thus have the potential to strengthen the response to global issues.

It can be said that measurement of GHG emissions using these standards and guidelines is an important step for evaluating and improving environmental loads as part of the sustainability strategy of an organization or company. Which standard is selected will depend on the purpose of the organization, industry, local regulations, available resources, *etc*. Large companies and organizations may also use a combination of the elements of these standards. Regardless of which standard or guideline is selected, proper understanding and use of the selected standard/guideline is essential, but in particular, this paper will explain the GHG Protocol and the theoretical and practical methods for evaluating emissions in Scope 1, Scope 2 and Scope 3 in supply chains.

3. OVERVIEW OF THE GHG PROTOCOL

The GHG Protocol Corporate Accounting and Reporting Standard (GHG Protocol) is an international framework for measurement, reporting and verification (MRV) of GHG which was developed jointly by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) in 1998, and now is used by companies and organizations when evaluating GHG emissions and establishing sustainable business strategies. The GHG Protocol is widely accepted as an important tool for supporting evaluation and reduction of emissions as part of a sustainable management strategy, and is mainly used by companies and organizations as a tool when evaluating their own GHG emissions and managing impacts on the environment.

The GHG Protocol has the following distinctive features.

1) Coverage of emissions sources: The Protocol covers GHG emissions across all the activities of the reporting company, including emissions from process and combustion of fuel, emissions in the process of generating electric power for use, and other emissions related to the supply chain and life cycles of products.
2) Methods of calculating and reporting GHG emissions (GHG emissions accounting reporting methods): The Protocol

provides methods for GHG emissions accounting reporting methods for each Scope. Companies are required to select the proper methods for detailed measurement and reporting of the GHG emissions attributable to their own activities.

3) Response of companies to sustainability: The GHG Protocol supports the efforts of companies to develop sustainable management strategies. Based on evaluations of the amount of GHG emissions, companies can implement countermeasures such as energy-saving measures, introduction of renewable energy, *etc*., and can construct a sustainable business model that reduces loads on the environment.

4) International standardization: Because the GHG Protocol is widely recognized as a common international framework, it is used by companies and organizations in countries throughout the world. This facilitates evaluation and comparison of the GHG emissions of different countries and regions.

By chapter, the content of the GHG Protocol is as follows.

Chapter 1 GHG Accounting and Reporting Principles Guidance on the principles of accounting and reporting of GHG emissions.

Chapter 2 Business Goals and Inventory Design

Chapter 3 Setting Organizational Boundaries Guidance for setting organizational boundaries.

Chapter 4: Setting Operational Boundaries Guidance on setting operational boundaries.

Chapter 5: Accounting for GHG Reductions

Chapter 6: Tracking Emissions Over Time Guidance on setting temporal performance data.

Chapter 7: Identifying and Calculating GHG Emissions

Chapter 8: Managing Inventory Quality

Chapter 9: Reporting GHG Emissions Guidance and calculation and reporting of GHG emissions.

Chapter 10: Verification of GHG Emissions

4. CALCULATION OF GHG EMISSIONS BY THE GHG PROTOCOL

The GHG Protocol provides the classification of Scope 1, Scope 2 and Scope 3 for GHG emissions accounting.

Fig.1 Source: Ministry of the Environment materials, “Toward calculation and reduction of supply chain emissions”.

1) Scope 1: Direct emissions = Direct emissions of GHG by the reporting company (fuel combustion, industrial processes)

Scope 1 means GHG emissions attributable to the direct activities of the reporting company. Concretely, emissions of the following GHG are included:

① Combustion of fuels: GHG emissions generated when using fuels owned by the company. For example, emissions from gasoline- and diesel-fueled vehicles and combustion in gas boilers are included.

② Emissions from processes: GHG emissions generated by the manufacturing processes or industrial processes of a company. As examples, this includes the production of cement and steel.

③ Leaks: GHG emissions generated unintentionally by activities of the reporting company. As examples, this includes leaks of cooling liquids and methane gas.

Scope 1 GHG emissions are emissions that can be controlled directly by the reporting company itself, and can be reduced by optimization of fuel use and manufacturing processes, *etc*.

2) Scope 2: Indirect emissions = Indirect emissions accompanying the use of electricity, heat and steam supplied from another company.

Scope 2 refers to GHG emissions indirectly related to the activities of the reporting company, and mainly includes GHG emissions due to consumption of electric power and the use of heat or steam.

3) Scope 3: Other indirect emissions = Indirect emissions other than Scope 1 and Scope 2 (emissions by other companies related to the activities of the company)

Scope 3 indicates other GHG emissions indirectly related to the activities of the reporting company, and includes the company's supply chain and the life cycles of sold products. Since direct control of Scope 3 GHG emissions by the company itself is difficult, the cooperation of supply chain companies, the effect on customers, *etc*. is considered. However, reductions are possible by improvement of supply chain management and manufacturing processes, *etc*. Concretely, Scope 3 includes the following three types of emissions, which are further classified in 15 categories:

① Purchases from suppliers: GHG emissions when the company purchases raw materials or products.

② Use of sold products: GHG emissions generated when consumers use products manufactured by the company. For example, this includes emissions associated with office supplies and various types of purchased services.

③ Waste treatment: GHG emissions generated when the treatment of wastes is consigned to an outside contractor.

15 Categories in Scope 3

Scope 3 categories		Corresponding activities (examples)
1	Purchased good and services	Purchases of raw materials, outsourcing of packaging, purchases of consumables.
2	Capital goods	Increases in production equipment (in the case of equipment constructed or manufactured over multiple years, reported in the final year when construction/manufacture is completed).
3	Fuel- and energy-related activities not included in Scope 1 or Scope 2	Upstream processes (extraction, refining, *etc*. of purchased fuels. Upstream processes (extraction, refining, *etc*. of fuels used in power generation) of purchased electric power.
4	Transportation and distribution (upstream)	Inbound logistics purchased by the reporting company, transportation and distribution between the company's own facilities, outbound logistics (where the company is the owner).
5	Waste generated in operations	Transportation and treatment of waste by outside contractors (excluding waste having value, i.e., recyclable content).
6	Business travel	Business travel by employees.
7	Employee commuting	Commuting by employees.
8	Leased assets (upstream)	Operation of leased assets leased by company. (Because these are reported in Scope 1 and Scope 2 in the accounting, reporting and disclosure system, most leased assets do not fall under this category.)
9	Transportation and distribution (downstream)	Shipping transportation (transportation after the company is the owner), storage in warehouses, retail sales.
10	Processing of sold products	Processing of intermediate products by downstream companies.
11	Use of sold products	Use of products by users.
12	End-of-life treatment of sold products	Transportation and treatment of products upon disposal by users.
13	Leased assets (downstream)	Operation of leased assets owned by the company as lessor and leased by other entities.
14	Franchises	Operation of franchise system members supervised by the reporting company falling under Scope 1 or 2.
15	Investments	Operation of investments, including equity and debt investments and project finance.
Others (optional)		Daily lives of employees and consumers.

Source: Ministry of the Environment materials, “Toward accounting and reduction of supply chain emissions”.

5. SUPPLY CHAIN GHG EMISSIONS ACCOUNTING PROCEDURE

The procedure for evaluation of supply chain GHG emissions includes data collection and measurement, the methodology of GHG emissions calculations, and consideration of uncertainties. The following explains the details of these respective items.

1) Data collection and measurement

The amount of GHG emissions generated by various activities in the supply chain is quantified by data collection and measurement. The main procedure is as follows.

① Determination of the scope: First, decide the target scope for evaluation (Scope 1, Scope 2 or Scope 3). It is important to clarify which scope applies to activities in the supply chain.

② Establishment of a data collection plan: Understand the activities in the supply chain, and plan the range and frequency of data collection. In some cases, cooperation with suppliers and cooperating companies involved in the supply chain may be necessary.

③ Data collection: Based on the data collection plan, collect data on the amounts of energy use, fuel use, purchased raw materials, *etc*. These data are necessary in evaluations of the amount of GHG emissions attributable to each activity in the supply chain.

④ Improvement of measurement accuracy: It is important to collect data that are as accurate as possible. Therefore, efforts to improve the reliability of measurements are necessary, for example, by improving the accuracy of measuring equipment, *etc*.

2) Calculation of emissions

In calculating supply chain GHG emissions, the appropriate calculation methodology for each scope is to be used. The following is a simple explanation of the measurement methodologies for each scope.

① Scope 1 (direct emissions)

- 1. Collect the types and consumption of fuels used (petroleum, natural gas, *etc*.) = Amount of activity, and the GHG emissions generated by designated processes = Amount of activity
- 2. Confirm the emission factors (emissions unit values) of the GHG generated by combustion of each fuel.
- 3. Volume of greenhouse gas emission (t-CO_2e) = Amount of activity x Emission unit value (emissions per unit of activity).

② Scope 2 (energy-derived indirect emissions)

- 1. Amount of use of energy such as purchased electricity, steam, HVAC, *etc*. = Amount of activity
- 2. Confirm the emissions unit value corresponding to each type of energy used.
- 3. Volume of greenhouse gas emission (t-CO_2e) = Amount of activity x Emission unit value.

③ Scope 3 (other indirect emissions)

Although Scope 3 is divided into 15 respective categories, there are two accounting methods for the emissions of each category, as shown in - 1. and - 2. below. Examples of calculation are shown in - 3.

- 1. Submission of emission data by the related trading partners (method using primary data).
- 2. Reporting by trading partners in the form of “Total emissions (** tons) in production for the reporting company in fiscal year @@”. This method uses the calculation formula “Emissions = Amount of activity x Emission unit value”.

• The reporting company collects the amount of activity.
• The emission unit values are obtained from an external database or provided by the trading partner.

- 3. Examples of calculation

• Calculation of emissions related to raw material purchases (Scope 3, Category 1)
  - Collect the amounts of raw materials and parts necessary in production of products.
  - Confirm the emission unit value related to the production of each raw material and part, and calculate the volume of GHG emissions by multiplying the amounts purchased by the emission unit value.
• Calculation of emissions related to product transportation (Category 4)
  - Collect the product transportation distances and the means of transportation (truck, ship, airplane, *etc*.)
  - Confirm the emission unit value corresponding to each transportation distance and means of transportation, and calculate

the volume of GHG emissions by multiplying the transportation volumes by the emission unit value.

- Calculation of emissions related to employee commuting and business travel (Category 6, 7)
  - Collect the distance and means of employee commuting and business travel.
  - Confirm the emission unit value based on the distance and means of transportation, and calculate the volume of GHG emissions by multiplying the amounts of commuting by the emission unit value.
- Calculation of emissions related to waste treatment (Categories 5, 12)
  - Collect the types of waste and their treatment methods (disposal, recycling, incineration, *etc*.), confirm the emissions unit values for each treatment method, and calculate the GHG emissions by multiplying the volumes of each type of waste by the emission unit value.

*Please refer to the guidance provided by the Ministry of the Environment, *etc*.
https://www.env.go.jp/earth/ondnaka/supply_chain/gvc/estimate.html

3) Consideration of uncertainties

In evaluating supply chain GHG emissions, it is important to consider the uncertainties accompanying measurement and data collection. As a method for understanding the effects of data uncertainty on evaluations of emissions and obtaining highly-reliable results, the following points are to be considered.

① Evaluation of uncertainties: Evaluate the uncertainties accompanying data collection and measurement.
② Effects of uncertainties: Corrections may be made considering the effect of data uncertainty on the amount of emissions. Corrections are to be made based on a statistical technique that takes uncertainty into account.
③ Reporting of uncertainties: The results of evaluations of uncertainties are to be reported appropriately in the report of GHG emissions. As a result, the reliability of the evaluation results can be shown clearly.

Evaluation of supply chain GHG emissions is a complex process, and proper data collection and measurement, use of the GHG emissions calculation methodology, and consideration of uncertainties are indispensable for obtaining accurate evaluation results.

6. SIGNIFICANCE OF THIRD-PARTY VERIFICATION OF GHG EMISSIONS ACCOUNTING REPORTS

Greenhouse gas emissions accounting reports are a method for quantitatively evaluating the GHG emissions generated by the reporting organizations and companies. Third-party verification plays an extremely important role in ensuring the reliability and accuracy of GHG emissions accounting reports. The following explains the significance of third-party verification in GHG emissions accounting reporting.

1) Enhancement of reliability and transparency

Third-party verification is a means of confirming that GHG emissions accounting reports are reliable. The accuracy and transparency of the information is enhanced by verification by an independent third-party verification organization. This increases trust in the content and methodology of GHG emissions accounting reports, and means that stakeholders can accept information on the organization's environmental performance with greater confidence.

2) Compliance with legal requirements and regulations

In some countries and regions, GHG reporting is required based on specific regulations and legal requirements. Third-party verification plays a crucial role in satisfying these requirements. GHG emissions accounting reports that have received third-party verification have legal credibility and support compliance with regulations.

3) Improvement of internal management

Third-party verifications also provide insights into the processes and data management methods of an organization. The verification process highlights points that require improvement in the methods of preparing GHG inventories and the reliability of data collection, and makes it possible for the reporting organization to obtain information for improving its own environmental management process.

4) Strengthening of external reporting

The GHG inventory is the basis for reporting to external stakeholders such as investors, customers, suppliers, *etc*. A GHG emissions accounting report that has received third-party verification can provide information, which has been verified by independent experts, to these stakeholders. This heightens the reliability and transparency of the reporting organization and strengthens external communications.

The third-party verification is an indispensable element for improving the reliability and value of the GHG inventory. By including third-party verifications in the process of evaluating the environmental impacts of an organization and promoting improvement measures, it becomes possible to realize more effective sustainability.

7. USE OF GHG EMISSIONS ACCOUNTING REPORTS AND DATA

The important points for the use of GHG emissions accounting reports and data are understanding the results of evaluations of GHG emissions, reporting and transparency of the results, and formulation and improvement of a GHG reduction strategy.

1) Understanding the amount of GHG emissions

An understanding of a company or organization's GHG emissions is an important source of information for understanding its efforts for sustainability and impacts on the environment.

① Comparison with the previous fiscal year: Trends in GHG emissions and the progress of improvement efforts can be understood by comparison with past results.

② Industry benchmarks: The reporting company's own performance can be evaluated by comparison with other companies in the same industry and the average of the industry as a whole.

③ Importance of GHG Protocol scopes: It is possible to understand the importance and effects of emissions in each of the categories of Scope 1, Scope 2 and Scope 3.

④ Risks and opportunities: An understanding of the amount of GHG emissions is also useful for identifying the risks of climate change and the opportunities of a sustainable business model.

2) Reporting and transparency of results

In GHG emissions accounting reports, sharing with internal and external stakeholders is important. Transparent reports not only enhance the trust of a company, but can also be an important means of communicating the company's initiatives for sustainability.

① GHG emissions accounting reports: Measurement methods, evaluation of uncertainties, the status of progress of initiatives, *etc*. are included in GHG emissions accounting reports.

② External reporting: GHG emissions accounting reports can be used in external reporting through the company's CSR Report, Sustainability Reports, official website *etc*.

③ Guidelines for sustainability reports: Transparency is secured by reporting based on international sustainability reporting guidelines (e.g., Global Reporting Initiative (GRI) Guidance).

3) Formulation and improvement of GHG reduction strategy

The company's GHG reduction strategy is formulated and improved based on its GHG emissions accounting reports. This makes it possible to reduce GHG emissions and promote efforts for sustainable business.

① Setting of GHG reduction targets: Based on the results of the GHG emissions accounting report, appropriate GHG emissions reduction targets are set, taking into account setting of concrete, measurable, realistic and planned targets.

② Construction of the GHG reduction strategy: Strategies such as countermeasures for activities with large GHG emissions, introduction of renewable energy and improvement of energy efficiency are established.

③ Continuous improvement: After the GHG strategy is implemented, periodical verification and improvement are carried out. It is important to grasp the results achieved and the issues to be addressed in order to continuously promote improvement of the strategy.

Use of GHG emissions accounting report data plays an important role in giving concrete form to the sustainability efforts of a company or organization. It is thought that transparent reporting and formulation/improvement of a GHG reduction strategy can contribute to a more sustainable management strategy.

8. ISSUES IN GHG EMISSIONS ACCOUNTING REPORTING AND THEIR SOLUTIONS

Various issues exist in GHG emissions accounting reporting. The following describes the respective issues and possible solutions.

1) Data availability and quality

- Issue: In GHG emissions accounting reports, a large volume of data is necessary, but there are cases where data is difficult to obtain or the quality of the data is inadequate. In particular, collection of information on the supply chain is sometimes difficult.
- Solutions:
  - To improve collection of supply chain data, it is important to strengthen cooperation with suppliers and build a consensus on the provision of data.
  - Efficient data collection can be realized by utilizing technologies that automate the data collection process.
  - To improve the reliability of data, introduce proofreading and verification processes to secure data quality.

2) Issues related to methodology and standardization

- Issue: GHG emissions accounting reporting is a complex process, and differences in methodology and a lack of standards can be problems. There is a possibility that calculation results may differ due to the use of different methods and standards.
- Solutions:
  - Unify calculation methods by introducing an international standard such as the GHG Protocol or ISO 14064-1.
  - With the cooperation of industry groups and experts, formulate a standard methodology and establish common industry-wide standards.
  - Describing the adopted methodology and calculation methods in a report, while maintaining transparency, will enable comparisons with the evaluations of others.

3) Communication with stakeholders

- Issue: In some cases, communications with stakeholders regarding the results of GHG emissions accounting reports and the company's initiatives for sustainability are inadequate. Transparency and dialogue are important for responding to the expectations of stakeholders.
- Solutions:
  - Make GHG reports and CSR reports publicly available, and share the results of GHG emissions evaluations with stakeholders.
  - Give priority to regular dialogues with stakeholders, collect stakeholder feedback, and use that feedback to improve the company's sustainability strategy.
  - Build a relationship of trust by implementing concrete countermeasures for important problems in line with the concerns and expectations of stakeholders.

Action on these issues is extremely important for ensuring the reliability of GHG emissions accounting reports and realizing a sustainable business strategy. Through improvement of data quality, promotion of standardization and transparent communications with stakeholders, companies can establish more sustainable business models.

9. OUTLOOK FOR THE FUTURE

1) Evolution of technology and improvement of data accuracy: In data collection and measurement, introduction of new technologies and improvement of data accuracy are expected. This is expected to improve the reliability of GHG emissions accounting reports and contribute to improved sustainability of supply chains.
2) Promotion of global standardization: Unification of methodologies for GHG emissions accounting reporting are expected as a result of progress in promoting international standardization. This is expected to facilitate comparisons between companies and improve evaluations of sustainability.
3) Strengthening of cooperation with stakeholders: It is important to strengthen communications with stakeholders, and to promote GHG emissions accounting reporting and practice of the company's sustainable business strategy based on the wishes of stakeholders.
4) Strengthening of partnership with suppliers: In improvement of the sustainability of supply chains, strengthening of cooperation and collaboration with suppliers is necessary. Joint promotion of sustainable business models by companies and their suppliers will enhance the possibility of realizing sustainability.

ClassNK (the Society) is involved in a large number of certification projects for GHG emissions accounting reporting, but remarkable expansion can also be seen in certification projects and the number of examinations derived from those efforts, including emissions accounting in the logistics sector, beginning with marine and air transport and also including land transportation, emissions offsetting using credits, green steel utilizing the mass balance method for steel makers, the SHIFT Project sponsored by the Ministry of the Environment, and the J-Credit Scheme, among others. The Society will continue to work to provide a diverse range of certification services responding to market demand, while also maintaining a high level of quality.

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Concept of Management and Application to Safety-Related Systems by RAMS

Jun YOSHINAGA*

1. INTRODUCTION (RAMS FOR RAILWAY)

1.1 Overview of RAMS

RAMS refers to the four factors of Reliability, Availability and Maintainability (RAM) and Safety. The functional safety standard for the railway sector, IEC 62278, is commonly known as “RAMS”.

This standard should perhaps be called “Railway RAMS”, but because there is no other international standard that considers Safety in conjunction with RAM and the expression RAMS has also taken root worldwide, the term RAMS will be used in this paper.

The RAMS standard specifies a procedure for achieving and demonstrating (explaining based on appropriate grounds) the requirements for the four factors of RAM and Safety which are required in railway products. Since it has rapidly become a de facto standard in overseas railway projects, applicability to RAMS is required in safety-critical products.

However, because there is no international framework equivalent to the IMO in the railway industry, and use of the RAMS standard is not legally required except in some countries, the general practice is to stipulate the application of RAMS in the specification between the parties concerned. Although RAMS is not required in domestic projects in Japan, the number of railway product manufacturers that are capable of utilizing RAMS is gradually increasing.

In comparison with the functional safety standards in other sectors, one distinctive feature of RAMS in the railway sector is the fact that it notes the importance of maintaining a balance among the four factors of RAM and Safety and with the life cycle cost (LCC), while continuing to prioritize safety.

Based on the example of RAMS for railways, this paper will describe the management methods applied by manufacturers and users in product development and product use by RAMS management methods, and the differences with the conventional thinking of aiming at “zero trouble”.

1.2 Reasons for Spread of RAMS

From the standpoint of railway companies in other countries, manufacturers (including integrators) are required to perform product development by procedures that conform to RAMS in order to procure safe products that are free of unexpected risks.

The following will use the development of a chair as a simple example so the reader can understand the general concept of product development based on RAMS. However, it should be noted that the original target of RAMS is products with embedded software programs.

Generally, the procedure when developing a chair is probably to consider the basic shape, and then study the strength and material of the legs.

It can be thought that this study is carried out bearing in mind safety measures for the risk of “failure under load” by considering the “target load that the chair should be able to withstand” and setting “strength of that value or more”.

Fig. 1 shows attempts to build three types of chairs. Intuitively, it seems that many risks can be mentioned in chair (2), and chair (3) which has a moving part. Next, let us consider the safety measures for these risks.

If an “object detection function (i.e., a sensor)” is considered to be an indispensable countermeasure for the risk of “catching one’s fingers”, which is a concern in chair (3), it would probably be hasty to select an expensive, high-reliability sensor. Rather, it would be more reasonable to create a mechanism which does not overlook possible problems by using multiple affordably-priced sensors. A study of this type corresponds to consideration of the balance of the four factors of RAM and Safety.

Safety measures are not limited simply to hardware and software, but also include various other types of measures, such as the user’s method of use, periodic inspections and so on. However, even so, risk which does not exceed a certain level, referred

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to as “residual risk”, is permissible (acceptable).

In RAMS, the series of studies outlined above is performed for each part and function in accordance with a planned procedure, and the multilayer verification of the results of implementation is carried out at key points. Finally, the plans, implementation, materials used in judgments, *etc*. of all activities are documented as documentary evidence.

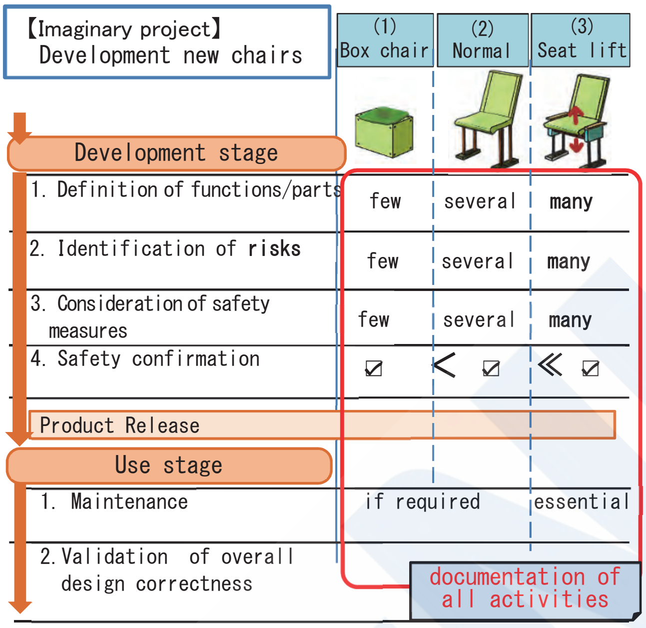


Fig. 1 Image of risk-based product development

In the procedures of functional safety standards such as RAMS, the amount of documentation increases when products have complex functions, but it is possible to demonstrate that adequate study and countermeasures for the requirements for RAM and Safety were developed based on the functional safety standard. Moreover, the scope of responsibility of the user and manufacturers is also clear.

In contrast, conventional methods can show a certain level of safety by conformity to a technical standard, *etc*., for example, “conformity to the guideline for furniture”, but the range of risks assumed by the technical standard is not clear.

In overseas projects, the product user is not necessarily an expert, which means that it is necessary to explain the grounds for judging that products are safe and the outlook for the reliability, availability and maintainability (RAM) of the product. In addition, because the common sense of the manufacturer is not the same as the common sense of the user, trouble may gradually develop later when a misunderstanding occurs. For these reasons, the RAMS standard requires preparation of documentation that make it possible to understand the range of risks assumed for the product, the grounds for judgment, and the division of responsibility between the manufacturer and the user. It is important that these points can be confirmed from this documentation.

In the example of the chairs, in the unlikely event of an accident, the grounds for safety can be found in the functional safety standard. That is, the documentation demonstrates that the system was developed in accordance with the functional safety standard, and all Safety requirements and RAM requirements (Fig. 2) were satisfied in the manufacturer’s development process. Moreover, it is also possible to investigate the cause of the accident in an objective manner.

On the other hand, in the conventional method, the basis of the development procedure is ISO 9001, and in this case, it seems that considerable labor would be required to demonstrate the validity of the procedure.

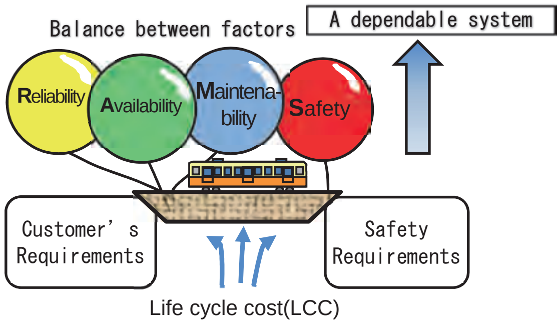


Fig. 2 System development based on functional safety

2. FUNCTIONAL SAFETY STANDARDS

2.1 Overview

The functional safety described up to this point is one method for ensuring the safety of safety-related systems and devices. In functional safety, it is thought that some kind of risk inherently exists in systems and devices. Functional safety is a method for providing systems and devices in which unacceptable damage will not occur, even if that inherent risk became evident as a result of an accident, human error, *etc*., by using safety functions.

The international standard IEC 61508 series "Functional safety of electrical/electronic/programmable electronic safety-related systems" has been published, and JIS C 0508 is the corresponding standard in Japan.

In Japan, application[1] of new risk management methods in which functional safety is applied to demonstration of the safety of machinery, whose safety had conventionally been confirmed by compliance with safety standards, has now begun accompanying the increasing complexity and difficulty of visualizing risk due to the application of IT technologies.

2.2 Functional Safety Standards by Industrial Sector

Since the object of the functional safety standard IEC 61508 is electrical/electronic/programmable electronic safety-related systems (E/E/PE) used in safety functions in all sectors, it is difficult to understand the image of the work, which is described in highly abstract words.

For this reason, functional safety standards in which the indexes to be studied and the stages of development are matched to the features of actual products have been developed for specific industrial sectors (Table 1), as exemplified by the RAMS standard for railways. It may be noted that a standard for the maritime sector have not been released at this point in time.

Table 1 System of functional safety standards [2] [3]

Classification	Examples of corresponding standards
Basic safety publication	IEC 61508 (JIS C 0508) "Functional safety of electrical/ electronic/programmable electronic safety-related systems"
Group safety publications	IEC 62278 Railway applications IEC 62279 Railway software safety ISO 26262 Road vehicles, electrical and electronic equipment IEC 62061 Industrial machinery ISO 13849 Safety-related parts of machinery control systems IEC 61513 Nuclear power plants

3. CONCEPT OF RAMS

3.1 Quality Control of Product Life Cycle

In functional safety, the product life cycle is divided into phases from the conceptual phase of the product though the decommissioning (end-of-life) phase.

Although IEC 61508 is divided into 16 phases, the RAMS standard is divided into 14 phases because some phases were consolidated. The details will be omitted here.

If the phases of the life cycle are generalized and grouped together, they can be classified in 3 phases as shown by the dotted lines in Fig. 3. Product release falls between the “Development stage” and the “Use stage”. With release, product development work is substantially completed, and work generally falls under the category of after-service, such as inspection, repair, *etc*. However, in the case of RAMS, activities that are carried out after release in connection with the RAM elements and Safety are also considered to be part of product development, and the manufacturer is required to prepare an integrated activity plan in advance of such work.

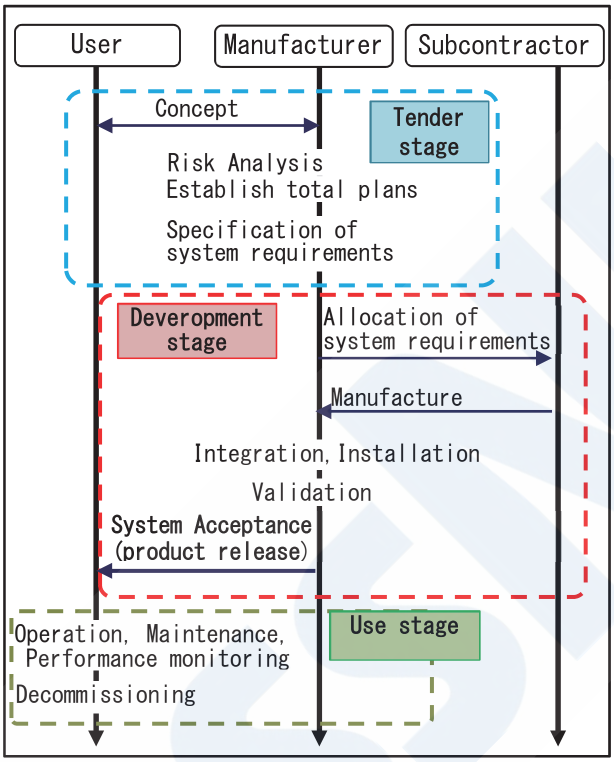


Fig. 3　Activities in product life cycle

Although the plans prepared for Safety and the RAM elements are called the “Safety Plan”, and the “RAM programme”, the actual names of these documents depend on each project. Both documents plan management activities such the setting of product targets and measures for their achievement, the personnel system, methods for design, manufacturing and validation, and the documentation to be prepared.

For the use stage, the plans also describe methods for confirming the status of the RAM targets calculated in the development stage, and the maintenance methods assumed as preconditions in the development stage. This information is provided to the user, as will be described later.

In activities based on the RAMS standard, those which are carried out in connection with the Quality Management System of an organization are “shall” requirements, indicating that the Quality Management System occupies an important position in RAMS (Fig. 4).

Although both plans are prepared prior to the start of product design and describe general matters, the RAMS standard attaches importance to plans that are consistent throughout the entire life cycle in order to control quality across the total life cycle of the product. For example, if a plan is prepared, it is possible to check the implementation of the plan, and disorderly (unplanned) activities, such as arbitrary additions and revisions to specifications by unplanned procedures, are not permitted (because the validity of disorderly activities cannot be checked, an increase in the potential risk is a possible). Furthermore, these plans make it possible to communicate all necessary information to the user completely. As described later in section 3.2.2, this has also become an important concept for securing software quality.

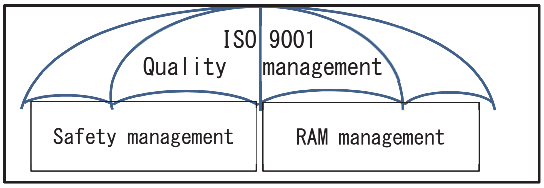


Fig. 4 Ensuring safety under quality management

3.2 Types of Failures and Their Countermeasures

The RAMS standard defines the following two types of failures and applies measures suitable for their distinctive features (Fig. 5). Since it is thought that many devices are now E/E/PE devices with embedded software, both types of measures are necessary in such cases.

(1) Random failures: Failures that occurs probabilistically.

(2) Systematic failures: Failures that occur under a specific combinations of inputs or specific environmental conditions.

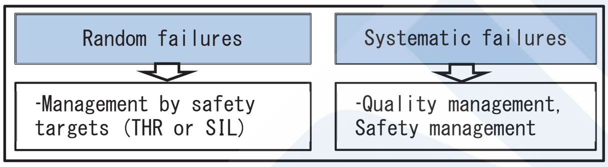


Fig. 5 Types of failures and their countermeasures

3.2.1 Countermeasures for Random Failures

Random failures occur probabilistically due to poor workmanship or deterioration of hardware. Because the effect assessment will depend on the severity and frequency of the failure, which types of hazards occur with what the degree of severity and frequency (risk) is important.

Therefore, for random failures, the necessary target of the system (THR: Tolerable Hazard Rate, or SIL: Safety Integrity Level) is allocated to each hazard, as shown in Fig. 6 (where the hazard is “loss of guiding function (derailment)”), and safety measures are taken to achieve this target. The safety of the system as a whole is protected by communicating the allocation rate of the system safety requirements to subcontractors.

In practical work, the SIL obtained by converting THR by Table 2 is frequently used. When subsystems are defined, the failure target (target failure rate) for the subsystems may also be decided in advance in some cases.

In allocations, targets that are higher than necessary to individual subsystems will result in unnecessary complexity, and is also a cost factor. Therefore, rational allocation is consistent with the concept of RAMS, which places importance on balance.

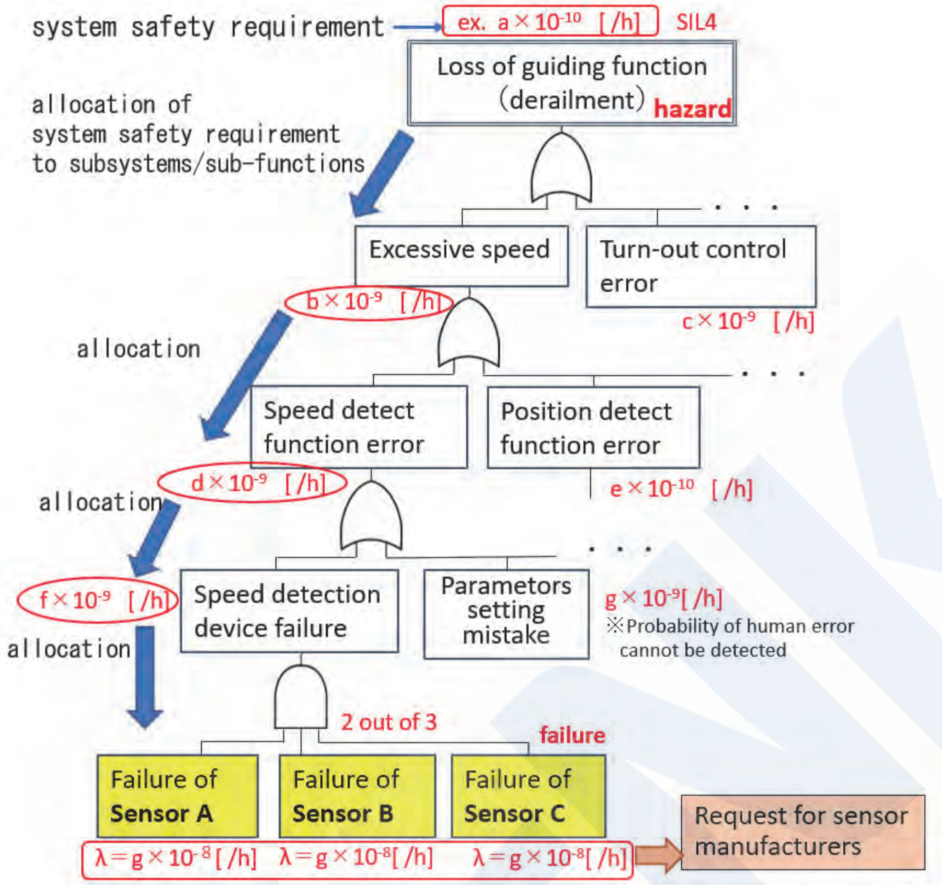


Fig. 6 Example of THR allocation to subsystems

Table 2 THR/SIL conversion

Average Tolerable Hazard Rate (THR) targeted by safety function	Corresponding SIL
< $1x10^{-8}$ [/h] to $1x10^{-9}$ [/h]	SIL 4
< $1x10^{-7}$ [/h] to $1x10^{-8}$ [/h]	SIL 3
< $1x10^{-6}$ [/h] to $1x10^{-7}$ [/h]	SIL 2
< $1x10^{-5}$ [/h] to $1x10^{-6}$ [/h]	SIL 1
≤ $1x10^{-5}$ [/h]	SIL 0

Source: IEC 61508-1 Ed. 2.0 Table 2 (with partial revisions)

Remarks: In case of E/E/PE systems that operate in response to requirements (high frequency) and E/E/PE systems that operate continuously.

3.2.2 Risk Reduction Measures for Systematic Failures

Systematic failures are typically failures that are built into a system, such as software bugs and design errors due to mistakes in work instructions. They do not occur probabilistically (randomly), but rather, will invariably occur when a specific set of conditions exists.

As risk reduction measures for this type of failure, measures to prevent built-in failures and detect human error, e.g., inspections, *etc*., are implemented by applying management equivalent to the Tolerable Hazard Rate (THR), or “Techniques and Measures” (hereinafter, “T&M”).

The distinctive feature of the management approach is Verification or Validation at each phase by a competent person. T&M refers to know-how, that is, knowing which measure is necessary when a product with a certain SIL target is to be manufactured, as shown in the related RAMS standard in Table 3. Here, higher SIL values mean a larger number of requirements is applied.

Since products developed by conventional T&M do not agree perfectly with the T&M described in the standard, even products with excellent quality may not conform to the standard. To avoid this situation, it is important, in future development, to conform to the T&M of the functional safety standard as far as possible, and to record the reasons for points where differences occur.

Table 3 Example of T&M of standard

Technique/Measure	SIL0	SIL1	SIL2	SIL3	SIL4
4. Functional testing	M	M	M	M	M
5. Checklists	R	HR	HR	M	M
9. Walkthrough	R	R	R	HR	HR

Symbols:

M: Mandatory

HR: Highly recommended

R: Recommended

Source: IEC 62279 Ed. 2.0 Table A.11 (excerpt)

3.2.3 Risk Analysis for Safety

Although the definition of "safety" in functional safety standards differs in each standard, "safety" is generally defined as "freedom from unacceptable risk".

"Risk" is defined as the "combination of the probability of occurrence of harm and the severity of that harm". Therefore, risk increases as the frequency of occurrence increases and the degree of harm becomes more severe. Whether risk is "tolerable" or not is extremely important, and deciding this correctly based on appropriate grounds, such as a field study of the actual condition of existing products, is indispensable for realizing a well-balanced system.

On the other hand, as the "residual risk" (Fig. 7) which remains even after risk reduction measures are taken, a level of risk that can be judged to be tolerable by society (socially acceptable) is allowed to remain in products, and is not reduced to zero.

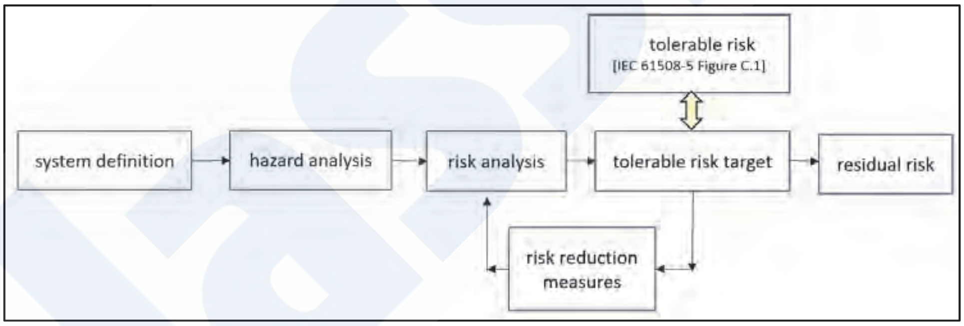


Fig. 7 Flowchart of risk reduction

Fig. 4 is a matrix of the frequency of occurrence of risk and the severity of harm. The manufacturer determines the concrete frequency of occurrence and severity, and takes risk reduction measures to eliminate or reduce risk at least in the categories of "Intolerable" and "Undesirable" based on a Failure Mode and Effects Analysis (FMEA), as shown in the examples in Table 5 and Table 6. In the FMEA, in addition to the Table 5, European manufacturers also study maintenance methods suitable for the part concerned (as discussed in section 5.1 below).

Although the current condition of the failure rate is desired when assigning frequency levels of risk and conducting an FMEA, it is difficult for individual manufacturers to determine this kind of information. In addition, although the target of legal regulations related to safety in the use stage is the actual manifestation of risks, unfortunately, neither laws and ordinance nor the RAMS standard defines the "socially acceptable level" of risks. This means that manufacturers must decide their targets for Safety and RAM by referring to the user's requirements, the principle of ALARP ("as low as reasonably practicable") [4] or the like.

This information is summarized in documentation called a "Safety Case", as shown in Fig. 8, which is defined as a "documented demonstration that the product complies with the specified safety requirements".

From the viewpoint of using this information to demonstrate the safety of the product to those concerned, it is desirable to list the conceivable risks in a matter-of-fact manner, without discarding or selecting any particular items. Moreover, it is also necessary to trace the relationship of the risk reduction measures, grounds for judgment reasons and user's safety requirements in the documents of the product, which can be considered a unique feature of the functional safety .

Table 4　Safety risk assessment matrix

Frequency of occurrence of a hazardous event	Severity of risk			
Frequent	Undesirable	Intolerable	Intolerable	Intolerable
Probable	Tolerable	Undesirable	Intolerable	Intolerable
Occasional	Tolerable	Undesirable	Undesirable	Intolerable
Remote	Negligible	Tolerable	Undesirable	Undesirable
Improbable	Negligible	Negligible	Tolerable	Tolerable
Incredible	Negligible	Negligible	Negligible	Negligible
	Insignificant	Marginal	Critical	Catastrophic
	Severity levels of hazard consequence			

Source: IEC 62278 : 2002 Table 6 (excerpt)

Table 5　Example of functional FMEA

ID	ITEM/Function	Fault	Fault consequence	Existing Measures
R1	Invertor	current velocity data loss	halt	warning
	. . .			

Table 6　Example of design FMEA

ID	ITEM /Function	Fault	Potential			Result			
			Sev	Occ	RPN	Mitigation	Sev	Occ	RPN
M1	Invertor	current velocity data loss as a result of wrong input	2	3	6	add input data rationality check function	2	1	2
	. . .								

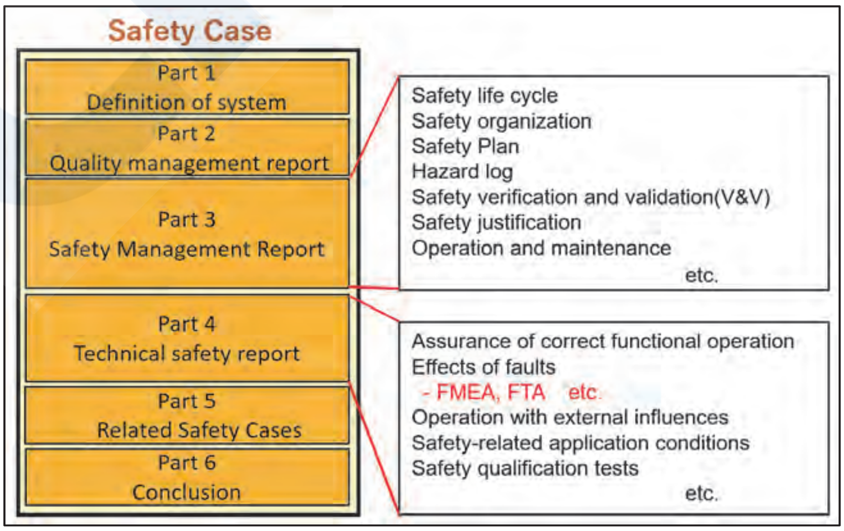


Fig. 8　Composition of Safety Case (documentation demonstrating compliance with safety requirements)

4. CONCEPT OF RAM MANAGEMENT

4.1 Factors of RAM

While assuming the safety of products as a given, product users prioritize Reliability, Availability and Maintainability (RAM), which are related to life cycle cost (LCC). Because particularly high importance is placed on the factors of RAM in railway rolling stock, some procurement specifications specify concrete numerical values.

Because standards do not specific concrete indexes for each of the factors of RAM, and only provide several examples (e.g., CLC/TR 50126-3, EN 50657), an index suitable for the product is selected. The main items are shown in Table 7.

For example, if the non-available ratio of a train is 5 [min/year], the availability (A) requirement is 9.5 x 10^{-6} (9.5 x 10^{-4} [%]). Assuming that a train experiences failures that result in a stop at a rate of 2/100 000 [km of train travel], MTBF (Mean Time Between Failures) = 50 000 [km of train travel] is required.

Table 7 RAM and Safety indexes

	Outline	Main indexes
Reliability (R)	Ability to perform as required for a given time interval under given conditions.	MTBF [h], MDBF[km] (Mean Time Between Failures), $\frac{1}{\lambda_S+\lambda_D}=\frac{1}{\lambda}$ [1/h]
Availability (A)	Ability to be in a state to perform as and when required, under given conditions.	$\frac{MTBF}{(MTBF+MTTR)}$ [%] $\frac{\mu}{\lambda+\mu}$ [%]
Maintainability (M)	Ability to be retained in, or restored to a state in which it can perform as required, under given conditions of use and maintenance.	$\mu=\frac{1}{MTTR}$ [%], MTTR [h] (Mean Time To Repair)
Safety (S)	Ability to be free of unacceptable risk.	λ_D [1/h](Dangerous failure rate) MTBF-H [t] (Mean Time Between Hazards)

In this table, λ means a failure rate. In terms of safety, the "dangerous failure rate" is important. Although there are various classification methods, here, the failure rate used in the table is given by the following Eq. (1), based on the safe failure rate λ_S and the dangerous failure rate λ_D.

It can be said that "failsafe" design, which enables safe operation during failures, is also an architecture for improvements to reduce the ratio of λ_D.

$$\lambda = \lambda_S + \lambda_D \tag{1}$$

However, λ is to be a constant value over time that satisfies $0 \leq \lambda \leq 1$.

MTBF and MDBF represent the mean time or mean distance (km) that a train travels between the occurrence of failures, as shown in Fig. 9. For example, a system MDBF = 100 000 km means that one failure occurs in each 100 000 km of travel on average.

MTTR in the table shows the time from a failure until the completion of repairs, also including the time necessary to make arrangements for the repairs and maintenance parts, for a system premised on repair or exchange of parts.

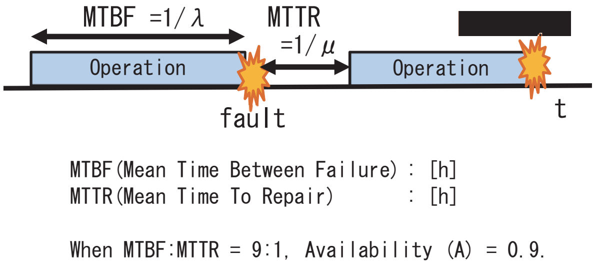


Fig. 9 Concept of Mean Time To Repair

The reciprocal μ of MTTR is the repair completion ratio per unit of time [1/h], and is suitable for cases in which the time until completion of maintenance is probabilistic. In making repairs of railway rolling stock, there are some cases where repairs can be made immediately after a failure, and other cases where repairs must wait until late night. Therefore, this index is used in setting targets for the maintainability of products, for example, MTTR = 20 h (μ = 1/20).

To summarize this section, Reliability (R) is the ratio of the time or distance that a system functions, Availability (A) is the ratio of system operation in total time, and Maintainability (M) is the time required for repairs after a failure or the probability of repair (also including time for movement in addition to the net (actual) maintenance time). However, other indexes are also available.

Although maintainability is mainly defined in terms of repair, there are cases where maintainability also includes periodic inspections, lubrication (oiling), exchange of worn parts and cleaning work.

4.2 Setting and Allocation of RAM Targets

The allocation of system requirements for safety was described previously in Fig. 6. Among the RAM factors, particularly in the case of user requirements for Reliability, the manufacturer decides the target value of the system and then allocates Reliability targets to the subsystems.

Because an FTA (Fault Tree Analysis) for allocating Reliability rates would be too complex, the theoretical structure is simplified by a Reliability Block Diagram (RBD) according to IEC 61078, and Reliability is calculated for the system as a whole (see section 5.2).

To evaluate whether the result of the Reliability analysis is appropriate or not, the manufacturer also defines the severity and frequency of occurrence of failures for Reliability in the same as in the above Table 4 (Safety risk assessment matrix).

Table 8 shows an example of the risk assessment items related to parts installed in railway rolling stock. The condition of function maintenance is used as a judgment criterion for rolling stock parts. In many cases, MTBF (or MDBF) is used for frequency. Here, however, frequency is classified in terms that can be easily grasped and is easily understood by the user, such as the degree of the effect on safety, or the range of spread of effects.

Table 8 Example of risk assessment for Reliability

Severity	System failure mode	Impact to operation
Serious	Total system failure	Operation is impossible.
Large	Marginal functional failure (limit of acceptability)	Emergency operation
Small	Functional failure that does not reach the limit of acceptability.	Emergency operation
Negligible	Functional failure of a level that can be ignored.	Normal operation

Because Availability (A) is an element which is closely related to Reliability and Maintainability, as can been seen in Table 7, the Availability target exists in a relationship in which the target for Availability is achieved by achieving the targets for Reliability and Maintainability.

Maintainability (M) targets are set for the system and each subsystem, specifying the type of maintenance shown in Table 9 which is to be applied and the frequency of maintenance, based on a judgment considering the maintenance cost, MTTR and degree of involvement in safety.

The factors of RAM and Safety are closely interrelated. The targets of each factor are achieved through repeated study.

Table 9　Main types of maintenance

Type of maintenance	Outline
Preventive maintenance	Maintenance work performed regularly at specified intervals of time, travel distance, *etc*.
Corrective maintenance	Maintenance work performed when a failure or malfunction is detected.
Condition based maintenance	Maintenance work performed on reaching a predetermined index value based on condition monitoring.

5.　APPLICATION EXAMPLES OF THE BALANCE OF RAM AND SAFETY

In recent years, the reliability of condition monitoring technologies and general-purpose parts such as memory devices has improved. This chapter presents examples of studies on improvement of the RAM factors by using general parts, *etc*., while also avoiding any substantial effect on safety.

5.1　Reliability and Maintainability

As a result of advances in sensor technology, maintenance of parts that had conventionally been exchanged after a set period has now progressed to "condition based maintenance", in which parts are exchanged when advance signs of potential failure are detected.

As shown in Fig. 10, if it is possible to detect anomalies (signs of potential failure) and perform maintenance within the period (P-F interval) from the detection of a potential failure to the actual failure, it is rational to incorporate this method in functional devices that have characteristics which can easily detection potential failures.

Although this method is not suitable for systems which require a high level of safety, the MTBF of other systems can be extended by maintenance without performing major repairs.

European manufacturers strategically implement reliability improvement measures using maintenance, for example, by studying the reliability of the detection and display function for potential failures at the time of system design and including maintenance methods and cycles suited to the part concerned in the above-mentioned Functional FMEA in Table 5.

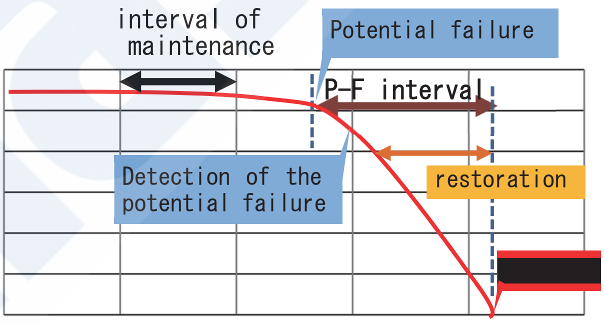


Fig. 10　Maintenance during P-F interval

5.2　Safety and Reliability

Fig. 11 shows an equipment configuration in which the same equipment is connected redundantly which is used in safety-related systems. This is a safety measure in which a "2 out of 3 (2/3) redundant system" is adopted in case the output of 2 units is in agreement in majority logic, and a 1/2 standby system switches to the standby system by a SW (switch) when a failure is detected.

Fig. 12 shows a failure of the total system (condition of function stop), that is, failure of equipment A, B and C that make up the 2 out of 3 redundant system.

These are example of the thinking when studying a system with the aim of cost reduction by using general parts without affecting safety. Here, equipment A, B and C are devices with the same failure rate λ, repair ratio μ, and dangerous failure rate

λ_D, and the failure rate of one of the 2 switches (SW) is expressed by (1 – p).

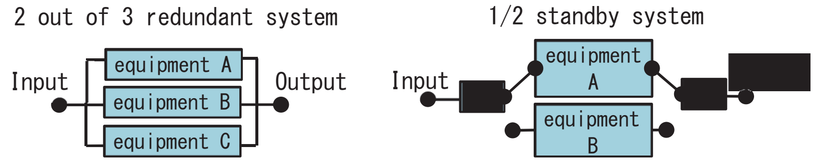


Fig. 11　Block diagram

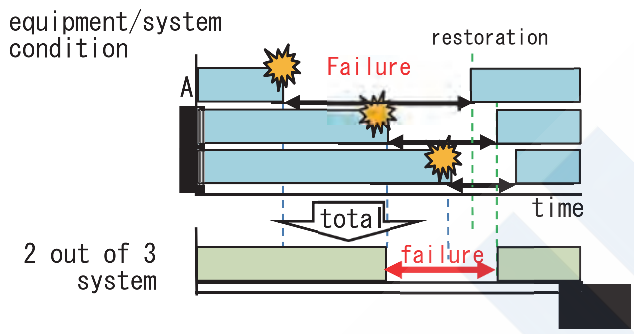


Fig. 12　Failure of 2 out of 3 redundant system

The safety of the 2/3 redundant system, $S_{2/3}$, can be expressed by Eq. (2) because it is the probability of cases other than that where 2 or more of the equipment units cause a dangerous failure at the same time. The safety of the 1/2 standby system, $S_{1/2s}$, can be expressed by Eq. (3) because it is the probability of cases for a switch failure and for the time when a dangerous failure of the equipment unit occurs.

$$\begin{aligned} S_{\frac{2}{3}} &= 1-\left({\lambda_D}^3+\ {}_3C_2{\lambda_D}^2(1-\lambda_D)\right) \\ &= 2{\lambda_D}^3-3{\lambda_D}^2+1 \\ &= (2\lambda_D+1)(1-\lambda_D)^2 \end{aligned} \tag{2}$$

$$S_{\frac{1}{2s}} = 1-\left(p\cdot\ \lambda_D+(1-p)\right)\ = p(1-\lambda_D) \tag{3}$$

λ_D :dangerous failure rate of equipment[1/h]
p :inverse of failure rate of two switches[1/h]

On the other hand, according to a reference by a US military research institute [5], the dangerous failure rate of the 2/3 redundant system, $\lambda_{2/3}$, can be expressed by Eq. (4), and that of the 1/2 standby system, $\lambda_{1/2}$, can be expressed by Eq. (5).

$$\lambda_{(n-q)/n} = \frac{(n)!\ \ (\lambda)^{q+1}}{(n-q-1)!\,(\mu)^q} \tag{4}$$

$$\lambda_{n/n+1} = \frac{n[n\lambda+(1-p)\mu]\lambda}{\mu+n(p+1)\lambda} \tag{5}$$

n :number of active units (n=3 in Eq.(4), n=1 in Eq (5))
q :number of units allowed to fail (q=1, in Eq.(4))
μ :repair rate[/h]
p: inverse of failure rate of two switches[1/h]

Using Eq. (2) to Eq. (5), reliability and safety were calculated by virtual numerical values, as shown in Table 10, for a system using parts which are highly reliable but require time for repair arrangements, and a system using parts which have a high failure rate but are readily available as "normal equipment", i.e., general parts. Both systems are virtual.

Although the calculations were based on the assumption that the failure rate of the normal equipment is 5 to 10 times higher (worse) than that of the high-reliability parts, it can be understood that the normal equipment shows values similar to those of the system using the high-reliability equipment, depending on the architecture.

An element that makes a large contribution to improved reliability is shortening of the repair rate μ of the normal equipment from 24 hours to 6 hours, demonstrating that improvement of the repair rate is effective for improving the RAM factors.

Table 10 Example of trial calculation of safety and reliability

	high reliable equipment	normal equipment
Parameters of single equipment	$\lambda=1\times10^{-5}$ $\lambda_D=1\times10^{-7}$ $\mu=1/24$ $=4.17\times10^{-2}$ $p=1-10^{-5}$	$\lambda'=5\lambda$ $=5\times10^{-5}$ $\lambda_D'=10\lambda_D$ $=1\times10^{-6}$ $\mu'=1/4$ $=2.5\times10^{-1}$ $p'=p=1-10^{-5}$
2 out of 3 redundant system	$\lambda_{2/3}=1.44\times10^{-8}$ $s_{2/3}=1-3\times10^{-14}$ (SIL 4 Corresponding)	$\lambda_{2/3}'=6.00\times10^{-8}$ $s_{2/3}'=1-3\times10^{-12}$ (SIL 4 Corresponding)
1 out of 2 standby system	$\lambda_{1/2}=2.50\times10^{-9}$ $s_{1/2}=1-1\times10^{-5}$ (SIL 1 Corresponding)	$\lambda_{1/2}'=1.05\times10^{-8}$ $s_{1/2}'=1-1\times10^{-5}$ (SIL 1 Corresponding)

Remarks: All figures in the above table are virtual value

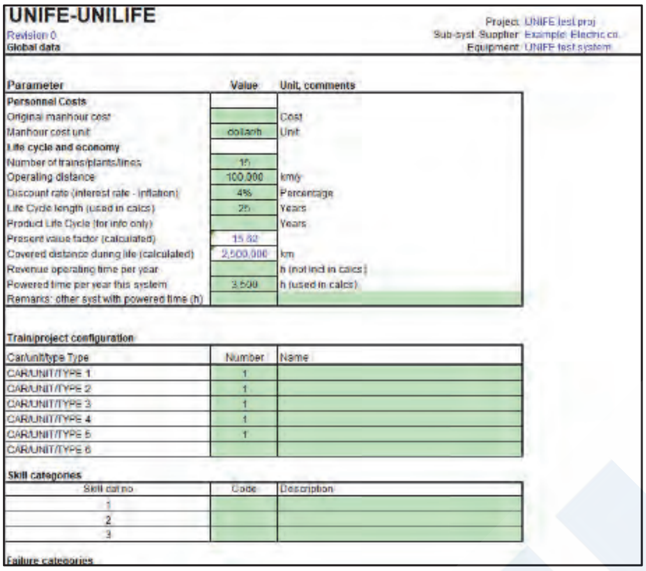
5.3 Calculation of Life Cycle Cost (LCC)

Regarding Life Cycle Cost (LCC), the RAMS standard states that safety shall not to be decided by cost, and notes the importance of a balance of Safety and the RAM factors, but does not provide specific requirements for LCC.

Since LCC is an important concern for users when determining RAM targets, in Europe, a calculation tool that uses the actual values surveyed by the industry in the European region as back data (historical data) has been developed (Fig. 13).

This tool has a structure in which accuracy increases as more detailed conditions are input, and is widely shared and used by manufacturers and users.

In Japan, a tool of this type is not available, and each manufacturer grapples with the issue of LCC independently. Although indispensable, this is a difficult problem because it is difficult for a single company to grasp. While an industry-wide effort is desirable, this is also confidential business information of users.



UNIFE-UNILIFE
Revision 0
Global data

Project: UNIFE test proj
Sub-syst. Supplier: Example Electric co.
Equipment: UNIFE test system

Parameter	Value	Unit, comments
Personnel Costs		
Original manhour cost		Cost
Manhour cost unit	dollar/h	Unit
Life cycle and economy		
Number of trains/plants/lines	15	
Operating distance	100,000	km/y
Discount rate (interest rate - inflation)	4%	Percentage
Life Cycle length (used in calcs)	25	Years
Product Life Cycle (for info only)		Years
Present value factor (calculated)	15.62	
Covered distance during life (calculated)	2,500,000	km
Revenue operating time per year		h (not incl in calcs)
Powered time per year this system	3,500	h (used in calcs)
Remarks: other syst with powered time (h)		

Train/project configuration

Car/unit/type Type	Number	Name
CAR/UNIT/TYPE 1	1	
CAR/UNIT/TYPE 2	1	
CAR/UNIT/TYPE 3	1	
CAR/UNIT/TYPE 4	1	
CAR/UNIT/TYPE 5	1	
CAR/UNIT/TYPE 6		

Skill categories

Skill cat no	Code	Description
1		
2		
3		

Failure categories

Fig. 13　LCC calculation tool “UNILIFE”

6.　ROLES OF USERS IN RAMS

Users of released products use those products in accordance with a document called an SRAC (Safety Related Application Condition), which summarizes the technical requests from the manufacturer to the user.

Although the SRAC is similar to a user’s manual, the SRAC is prepared based on the results of a risk analysis by the manufacturer, and describes the essential use conditions for avoiding manifestation of potential risks in a consistent manner from the viewpoint of preventing risk. The SRAC is also included in the Safety Case prepared by the manufacturer, and issued to the user.

On the user’s side, users are recommended to conduct the field data analysis called FRACAS (Failure Reporting, Analysis and Corrective Action System) shown in green in Fig. 14 on a regular basis. The achievability of the RAM targets is monitored based on the routine maintenance data and failures, *etc*. discovered in operation (shown in purple in Fig. 14), together with operational data.

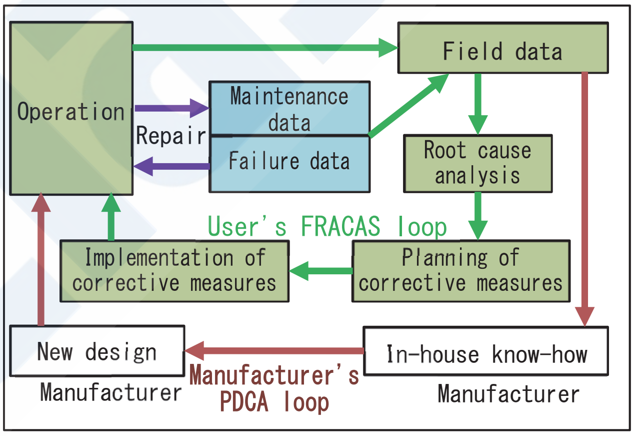


Fig. 14　PDCA cycle based on FRACAS analysis by user

Because there is concern that some type of malfunction or failure may occur if divergence is found as a result of this analysis, a root cause analysis and investigation are conducted, and improvements are carried out by implementing corrective action.

On the manufacturer’s side, the manufacturer investigates whether the RAM and Safety indexes studied in the product design stage are being achieved in response to contact from the user, or as an activity of its own Quality Management System.

If new risks are detected in this process, the product risk data in the Hazard Log are updated, and PDCA activities which utilize this data in future product development are performed.

The occurrence of product failures gradually decreases from a condition in which many initial failures occur and reaches a stable condition with a low failure occurrence rate over time. This is widely known as the “bathtub curve”. In overseas railway projects, a high cost penalty is often imposed for failure to achieve requirements (by contractual terms that impose a financial penalty for breach of contract on the manufacturer for failing to achieve the reliability target required in the product). Therefore, the timing of the judgment of achievement of requirements is important for both sides.

Since the timing of this judgment agreed between the user and the manufacturer in advance, the manufacturer monitors the condition of failure occurrence after product release and predicts the future trend.

If failure to achieve the requirements is predicted, manifestation of some type of malfunction or other risk is a possibility, so it is important to conduct a root cause analysis and take corrective action at an early timing in order to avoid the penalty. Mathematical prediction calculation methods such as the Erlang method, *etc*. are used for this purpose.

As described above, in the RAMS system, a risk-based approach is applied continuously to products, including in the use stage, by planning activities over the entire product lifecycle from product manufacturing, which also includes after product release, and operation, repair, and decommissioning.

As mentioned above, this is also related to the user’s confidential information, which means the range of information available to the manufacturer is frequently limited. Nevertheless, this is also a system that endeavors to improve product quality by identifying risks as far as possible and implementing measures.

7. CONCLUSION

This paper has presented an overview of the “RAMS” functional safety standard for railways, and has introduced techniques and risk-based concepts for ensuring safety by functional safety through RAMS.

Among the product development procedures based on RAMS, this paper has described distinctive concepts such as the types of failures and prioritization of quality control, and has also introduced examples of work performed by manufacturers and integrators, including the procedures for target setting for each of the elements of RAM and Safety and target allocation to parts, and the image of adjustment of each of the RAM factors with an awareness of cost.

The necessity of analysis activities for the RAMS factors based on field data, which are carried out by the user, was also described.

Finally, although it goes without saying, manufacturers in Japan provide prompt, carful after-service even without being asked, and this can be considered to be culture. On the other hand, in functional safety standards such as RAMS, a condition without controls such as planning, etc. is considered to be a disorderly state in which risks exist. Depending on how safety standards such as RAMS are used, they are also considered to provide a tool for demonstrating efforts in connection with product quality, safety and customer orientation which would otherwise remain unknown.

I hope that this paper will serve as a useful reference and can be of assistance in studies in the maritime sector, where technological development is progressing.

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Next-Generation Telecommunications Infrastructure

Yasuharu ADACHI*

1. INTRODUCTION

With expanding efforts to accelerate digitalization worldwide, telecommunications services that we depend on in our daily lives, such as communication and electronic payment for public transportation by personal computer or smartphone, have already been adopted widely throughout the world, and the high-capacity communication networks that support those services have become indispensable social infrastructure for our lives. The Cabinet Office of Japan has also proposed a vision called Society 5.0 and is strongly promoting the development of the telecommunications environment as a critical part of social infrastructure. Society 5.0 is defined as "a human-centered society that balances economic advancement with the resolution of social problems by constructing a system that integrates cyberspace (virtual space) and physical space (real space)." As part of Society 5.0, introduction and implementation of the concept of B5G (Beyond 5G)/6G, which is expected to become the next-generation wireless telecommunications infrastructure, will also drive the creation of new value.

In the world of the future, telecommunications will be something that we take for granted, like the air around us, and will become increasingly important as essential infrastructure, like electric power and water. Based on this social trend, this paper presents a commentary on the most recent technological trends related to digital communication networks, and discusses the importance of the telecommunications infrastructure in the maritime industry of the future.

Note: In this paper, the future 6G technology called B5G (Beyond 5G) is referred to as "B5G" in the following.

2. WHAT IS TELECOMMUNICATIONS?

Telecommunications is a means of sharing information between senders and recipients. Until now, people have tired various methods of communicating messages to counterparts separated by some distance.

In the world of ships, since the distant past, seafarers have also continued to develop methods for transmitting "visible information" to surrounding ships and persons on land by raising national flags and displaying navigation lights and emergency signals, and communicating the ship's own position and movements to surrounding vessels by using steam whistles and other auditory signals as "audible information". Even today, these communication techniques, some of which have been used for centuries, continue to play a key role in maintaining communications between ships and ensuring safe navigation.

The modes of telecommunication also evolve together with the technological progress and social change. At present, they can be divided into the two categories of telecommunications by fixed lines, which are suited for stability and high-speed telecommunications, and wireless telecommunications, which are superior in terms of mobility and flexibility. The primary role of telecommunications infrastructures, including the internet, is transmission by fixed lines, while wireless telecommunication tends to be used for "last one mile" delivery of messages. In telecommunications, this means that major data transfer routes and backbone networks are normally implemented using fixed lines. In telecommunications by fixed lines, physical cables are laid and information is transmitted over those cables, so large volumes of data can be transmitted with high efficiency, while simultaneously securing high bandwidth and reliability. For this reason, fixed lines are generally used as much as possible as transmission routes in the internal and external telecommunications infrastructure of companies and between the servers that make up cloud networks.

However, wireless telecommunications also play an important role in cases where it would be difficult to lay cables connecting transmitting/receiving devices, i.e., terminals, and in cases where the mobility of the terminals must be considered.

Wireless telecommunication is a communication method in which information is transmitted using radio waves. Wireless telecommunication began with transmission of Morse code signals by Marconi at the start of the 20th century, and analog signals

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were used until the advent of 1G (first generation) mobile wireless communication technology in 1980.

Although 1G considered a revolutionary technology at the time, the main application of 1G was voice telephone communications, and the cellphones themselves were not only bulky, but were also unsuitable for communication of data other than voice.

However, thanks to the complete transition to digital signals in the subsequent 3G technology, real-time video telephone became possible, although with some delay in transmission. The current 5G technology is capable of large volume, ultra-high speed communication, and makes it possible to share documents and search the internet while simultaneously online meeting.

In parallel with mobile wireless telecommunication technology, in which technological improvement has progressed from 1G to the current 5G and is now advancing toward the next-generation B5G/6G, a large number of new wireless communication technologies premised on digital systems are also reaching practical application, and today, the wireless communication technology called Wi-Fi (Wireless Fidelity), which is applied to short-range wireless transmission over distances within a few 10s of meters, and the short-range wireless technology called NFC (Near Field Communication), which enables instantaneous completion of non-contact information sharing and ticketing for public transportation system to mobile payments, are used in cities as a matter of course.

3. WIRELESS COMMUNICATION

Wireless communication is a telecommunications method in which information is transmitted to a remote location by propagation of radio waves through space.

Radio waves are one type of electromagnetic wave, which are formed by an electric field and magnetic field alternating at right angles. In this phenomenon, a magnetic field is formed in the surrounding area by an electric current passing through an object with a certain electrical charge, and an electric field forms naturally in the direction that prevents change in that magnetic field. Radio waves are transmitted through space by an interaction in which the magnetic field is formed again by changes in this electric field. Because the electric field and magnetic field propagate while mutually interacting with each other, they can be transmitted even through a vacuum which does not contain a vibrating medium, such as outer space. Electromagnetic waves also have a wide frequency range (band), and exist as waves with diverse properties as a result of having different wavelengths and energies.

In wireless communications, the frequency, wavelength and bandwidth of these electromagnetic waves are important elements that determine the propagation characteristics of communications. The mechanism of these basic propagation characteristics is the same in both analog and digital signals.

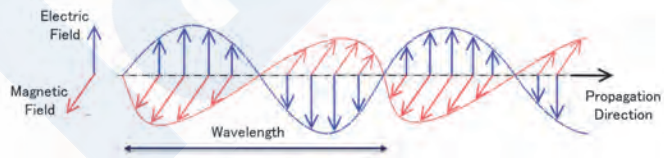

Fig. 1 Basic characteristics of radio waves

The following explains the wavelength, frequency and bandwidth of electromagnetic waves, and describes their relationship with propagation characteristics.

3.1 Frequency

The electromagnetic waves used in wireless communications are “waves”, and have the related properties of wavelength and frequency.

Wavelength is a periodic characteristic of continuous waves showing the distance to the same position in an adjoining wave. It is expressed in units of meters (m) or a multiple thereof (e.g., centimeter, millimeter, nanometer, *etc.*).

Frequency is the number of times that a wave is repeated in a unit of time, and indicates the number of waves that appear per second. Its unit is Hertz (Hz). One Hertz (1 Hz) means 1 vibration per second.

The propagation velocity of radio waves is constant regardless of frequency and is the same as the speed of light, that is, approximately 300000 km/s. The wavelength of a wave is obtained by dividing this propagation velocity by the frequency of the wave. The speed at which a wave is transmitted does not change regardless of whether its frequency is high or low. The relationship between wavelength and frequency is expressed by the following equation.

$$\lambda\ (wavelength) = \frac{c\ (speed\ of\ light)}{f\ (frequency)} \tag{1}$$

3.2 Data Bandwidth

Data bandwidth refers to the usable frequency width, and is calculated as the difference between the highest frequency and the lowest frequency. In other words, it is the frequency range that can be used to transmit data, and shows the speed of data (data transfer rate). The transfer rate is expressed in units of bits per second (bps), which indicates how many bits of data can be transferred in 1 second. For example, a data bandwidth of 1 Mbps means that a maximum of 1 megabit (1 million bits) of data can be transferred per second. The relationship between data bandwidth and the data transfer rate can be expressed by the following relational expression.

$$Data\ transfer\ rate = \frac{Data\ bandwidth}{Number\ of\ bits\ in\ a\ digital\ signal} \tag{2}$$

Because the basic concept is that a larger volume of data can be transferred as bandwidth increases, the transfer rate also becomes faster. However, the above-mentioned relational expression is used to calculate the ideal maximum data transfer rate, which means it is also necessary to take other factors into account in actual data communications; these factors include noise and signal modulation systems, error-correcting code, protocol overhead and the like. Therefore, the following equation is frequently used to find the data transfer rate.

$$R = B \times log_2(1 + \frac{S}{N}) \tag{3}$$

Here, R is the data transfer rate (bitrate), B is data bandwidth (Hz), log_2 is a base 2 logarithm, and S/N is the signal to noise ratio, where S is mean signal power and N is mean noise power. S/N expresses an effect of the quality and noise of a communication channel, and also has an effect on the performance of telecommunications system. Specifically, as S/N increases, a higher data transfer rate can be achieved. In addition, the number of bits of digital signals (bps/Hz) is determined by the digital signal efficiency and modulation method. In other words, if a more efficient modulation method is used, the number of bits per Hz will increase, and as a result, the data bitrate will also improve.

Although this relational expression is the framework of information theory and is used as an equation for calculating the data bitrate, in actual communication systems, it is necessary to determine the possible bitrate in consideration of various requirements.

3.3 Decay of Radio Waves

Low frequency radio waves have a long wavelength and generally have the propagation characteristic of passing easily through comparatively obstacles. Conversely, high frequency radio waves have short wavelengths and tend to decay or be reflected easily by obstacles, but have the potential to achieve high speed data transfer rates. Moreover, as implied by the wave nature of radio waves, it is assumed that radio waves will decay even in free space. The following concept based on the Friis transmission equation can be used to express the degree of this decay.

The power density PD of a radio wave, which controls signal transmission, has a value of the power, p, divided by the surface area of a sphere, $4\pi d^2$, having a radius equal to communication distance d, and therefore has the property of "attenuation proportional to the square of distance". For example, when the distance increases by 2 times, the area increases by 4 times, so the power density decreases to 1/4. This equation is expressed as follows:

$$PD = \frac{p}{4\pi d^2} \tag{4}$$

That is, in the decay of radio waves, this equation shows that the energy of the radio wave expands in space and becomes less dense as the communication distance increases, and as a result, the strength of the signal decreases. Attenuation of electric power is calculated as follows based on the Friis transmission equation.

$$PL = 20log_{10}\left(\frac{4\pi d}{\lambda}\right) \tag{5}$$

where, PL is propagation loss, d is the distance from the sender to the receiver, i.e., the distance from the transmitting antenna to the receiving antenna, and λ is the wavelength of the radio wave.

As can be understood from this equation, as tendencies of radio wave decay, decay not only increases as the propagation distance becomes longer, but also has the characteristic of “decay in inverse proportion to the square of the wavelength”.

Because these equations assume a free space, they do not take into account the effects of obstacles and reflection, scattering, diffraction, interference and the like. Therefore, when considering real-world telecommunications, a response based on those phenomena is necessary.

4. B5G FOR NEXT-GENERATION WIRELESS COMMUNICATION TECHNOLOGIES

Because the goal of digitalization in recent years is to realize an advance digital society that integrates physical space and cyberspace, it is essential to construct and realize a social infrastructure that can realize all the events that occur in the world as desired, without consciousness of physical constraints.

In order to construct and realize a secure next-generation infrastructure with high speed, large volume and low latency in the next-generation wireless communication network system B5G, which is scheduled for release in 2030 toward the achievement of this goal, it will be necessary to secure a wider data bandwidth in the region higher than the frequency bands used up to 5G.

In the technological improvements prior to 5G until now, improvement of telecommunications methods was promoted in a form that utilized the limited frequency bandwidth under approximately 300 GH_Z called millimeter waves (milliwaves), which had been used until that time. This was because higher frequencies have stronger electromagnetic wave straightness, and thus are unable to circumvent obstacles, and are also subject to large attenuation in the atmosphere, which means that transmission over long distances exceeding a few meters is technically difficult.

However, the market demands high transmission quality with these difficulties, and allocation of frequency bandwidth that can be used in telecommunications is also tightening. In response to these issues, technological innovation has progressed in recent years, as can be seen in semiconductor devices that use high frequency bands in telecommunications, polarization that captures the phase and the distribution of vibration directions of light, which is a further development of the wireless communication technology used to date, and the like. Thus, arrangement of the various groups of technology necessary in order to use new high frequency regions is beginning.

Backed by the above-mentioned technological advances, the first aim of B5G is to utilize the region up to 30 THz, which is called the “terahertz gap”, envisioning future use of frequencies up to 800 THz, which is the region of visible light that lies beyond the terahertz gap.

4.1 Wireless Communication Using Light

After first touching on the characteristics of radio waves and light shown in the following Fig. 2, wireless communication using light will be described.

Since the radio waves that control wireless communication and light are both electromagnetic waves and share the same space, they have the same basic characteristics for wireless communication described in Chapter 3, regardless of whether the transmission medium is radio waves or light.

The property that determines the transmission capacity when transmitting information is wavelength. If a wave oscillates gently, its wavelength is long and its frequency is low, and its information transmission rate is also slow to a corresponding degree. Conversely, rapid waves have a short wavelength and high frequency, and a large volume of information per unit of time can be transmitted due to the large number of waves that pass through a certain point, and in this case, the information transmission rate is fast. Thus, there is an inseparable relationship between wavelength and frequency.

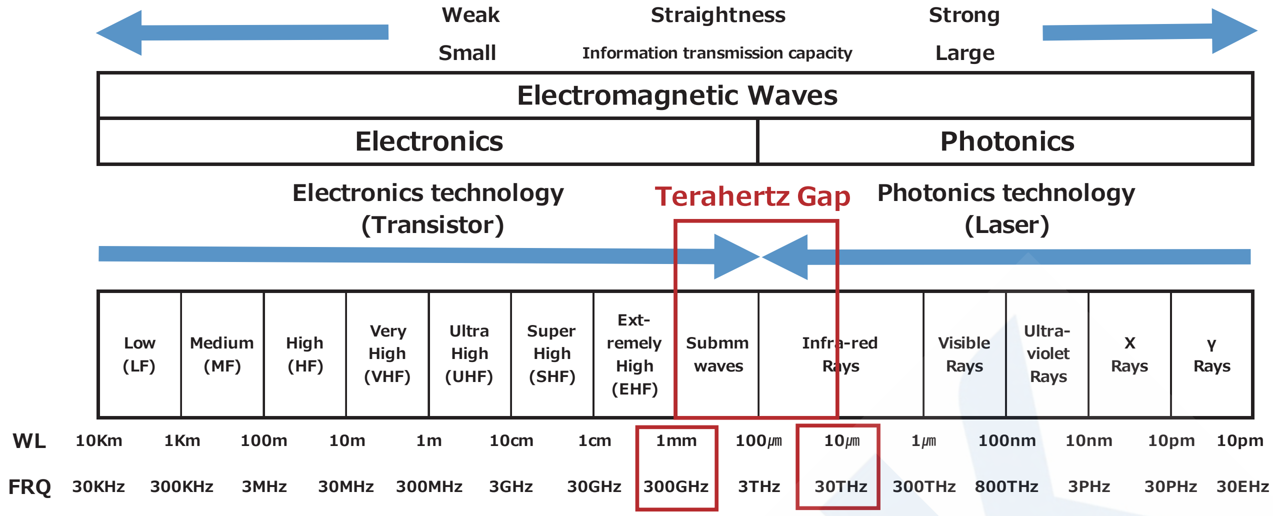

Fig. 2　Frequency bands of electromagnetic waves

Optical wireless communication uses light waves as the carrier wave, and is an access technology for sending and receiving data, in which a high frequency beam is transmitted directly through the atmosphere, forming a point-to-point communication link.

Due to the high frequency of light, it has a small energy loss during transmission is small and strong in interference and noise in comparison with electronic transmission. Because light has this feature, it is theoretically possible to achieve high speed data transmission over long distances and high signal quality. However, since light also has the transmission characteristic of strong straightness, obstacles to light propagation can easily occur due to various external factors such as physical obstacles, atmospheric scattering, absorption, weather conditions, *etc*. In addition, more than anything else, due to the high straightness of light, there are also technical situations in which good transmission is not possible without accurate positioning to receive the narrow light beam from the sending side. On the other hand, the high straightness of light is also a blessing, in that optical wireless communications are difficult to be intercepted.

A radio wave or this light “beam” indicates a shape in which light is focused and travels in a straight line. Light has the two natures of wave motion and particle behavior, and while it spreads due to its wave nature, it also has the characteristic of being focused as a beam. A focused beam of light traveling in a straight line is formed when light waves with a specified wavelength and the same phase and direction are generated so as to have an extremely high correlation. Unprecedently secure communication is possible by utilizing this characteristic of light in cybersecurity countermeasures.

With further progress and general application of these optical wireless communication technologies, cybersecurity countermeasures will also move to the next-generation phase, and accomplishment of safer wireless communication can be expected.

Optical wireless communication technologies are already used as an infrared communication function for cellphones and remote control devices for electronic products, and in recent years, a gradual expansion of their methods of use has been seen.

For example, in contrast to Wi-Fi, which uses radio waves, the technology called Li-Fi (Light Fidelity) has already been developed and is used in optical wireless communication. Like Wi-Fi, Li-Fi is also a wireless technology that uses the IEEE 802.11 standard. However, unlike radio waves, because Li-Fi optical wireless communication utilizes the infrared, visible light and UV optical frequency bands, interference is slight and Li-Fi does not cause radio disturbances. Use of optical wireless technology has also begun in hospitals, the cabins of passenger aircraft, nuclear power plants and other facilities where care is necessary when using electronic devices, suggesting that optical wireless communication using these characteristics of light has the potential to become an extremely promising new means of communication in the future.

It should be noted that the available range of frequencies and concrete definitions governing wireless communication are specified not only in international standards, but are also based on the laws of specific countries, industrial standards and the regulations in each region. Since different frequencies are allocated depending on the country or region, it is necessary to confirm the local regulations governing the frequency bands available for use. Ships are required to have appropriate wireless communication devices, and in some cases, restrictions are applied to the frequency bands that can be used by each device.

According to Chapter 1, Article 2 of Japan’s Radio Act, “radio waves” are defined as “electronic or magnetic waves of frequencies not exceeding 3 THz”. Therefore, until now, wireless communication meant communications using radio waves with frequencies of not more the 3 THz.

4.2 Terahertz Gap

The terahertz band is the electromagnetic wave region from roughly 300 GHz to 30 THz, centering on the frequency band around 1 THz, and has wavelengths from 1 mm to 10 μm. It is positioned at the boundary between light and radio waves that have a nature close to that of light (see Fig. 2). When compared with radio waves, the terahertz band has high resolution due to its short wavelengths, and it is a wide frequency band owning to its high frequencies. On the other hand, in comparison with light waves, it has high transmittance properties and scattering is slight. As an additional advantage, it is not susceptible to interference by surrounding radio waves due to distinctive features such as the molecular absorption effect (in which an absorption spectrum specific to certain molecules appears). For these reasons, the terahertz band has attracted worldwide attention as the electromagnetic wave frequency region with the greatest potential.

However, at such high frequencies, the ability of radio waves to avoid obstacle decreases and decay occurs due to water vapour in the air, *etc*. Long range transmission was also technically difficult because the decrease in radio wave generation and oscillation efficiency invites an increase in transmission loss. For these reasons, this frequency band was almost never used in telecommunications. Since it is also a region with many technical problems for both electronic technology and photonic technology, it was called the “terahertz gap”.

In order to use the terahertz band in telecommunications, technological innovation prioritizing hardware is necessary, beginning with directional antenna technology that enables sending and receiving only between target locations, as well as new circuit board materials that reduce transmission loss in high efficiency terahertz wave oscillation/detection devices in order to utilize the reflection and transmission properties of radio waves, and evaluation and control devices for high frequency propagation characteristics and communication links, *etc*.

High output characteristics are required in the light source used as the signal source in wireless communication, and high sensitivity and low noise characteristics are also required in receiving devices. The high sensitivity and low noise characteristics required here can be evaluated collectively as NEP (Noise Equivalent Power). NEP is the signal power equivalent to noise power, and is calculated by dividing the noise voltage of a receiver by voltage sensitivity. Similarly, the noise current can be found by dividing by the current sensitivity. In other words, the ratio of the magnitude of noise and sensitivity is important. Because noise power is proportional to bandwidth, the S/N ratio is improved by narrowing the bandwidth, but in this case, the response speed decreases. Therefore, it is necessary to determine the necessary bandwidth for the system to be implemented.

$$NEP = \frac{PA}{\frac{S}{N} \cdot \Delta f^{\frac{1}{2}}} \tag{6}$$

P: incident energy (W/cm^2)
A: light-receiving area of detector (cm^2)
S: signal output (V)
N: noise output (V)
Δf: noise bandwidth (Hz)

As can be understood from the above equation, NEP shows the incident quantity of light when the signal-to-noise ratio (*S*/*N*) is 1.

At present, the range of activity in research and development in the wireless communication field, which is being promoted worldwide centering on B5G, includes the development of devices and development of new wireless communication methods for utilizing the terahertz band, and international standardization envisioning the use of higher frequency bands.

5. OUTLOOK FOR NTN BY OPTICAL WIRELESS COMMUNICATION

NTN (Non Terrestrial Network), which is considered to be a next-generation communication network environment, is a concept which aims to use outer space as a telecommunications environment for providing high quality, stable communication services to places where it was difficult to construct infrastructure until now and areas where access to communications was limited until now. NTN will attempt to implement a global network environment that provides coverage to the entire Earth by three-dimensional linkage of geostationary orbit satellites, medium- and low-orbit satellites and high altitude platform stations (HAPS) flying in the stratosphere, and also includes linkage with base stations located on the Earth's surface. International standardization is currently underway in ITU-R WP5B (ITU Radiocommunication Sector Working Party 5B) and 3GPP RAN (Third Generation Partnership Project Radio Access Network).

It is thought that the wireless communication technologies described above will play an effective role as a means of communication by mutual linkage and connection between these artificial satellites. Although optical wireless communications on the Earth's surface are affected by various external factors, in outer space, ideal behavior close to that in free space becomes possible. By using optical wireless communication to connect various types of satellites, this will reduce the decay due to distance that occurs with radio waves, and improve the feasibility of power-saving, high speed, large volume communication. However, since there is a higher possibility that HAPS, which operate in the stratosphere, will be affected by the atmosphere, it will still be necessary to select and consider communication methods corresponding to the circumstances.

On the other hand, technological innovation from the user's standpoint is also demanded. The user's purpose is to send and receive large volumes of information at high speed by automatic selection of the optimum transmission route, without being conscious of transmission routes. Users also desire a communications infrastructure with no restrictions or gaps in the communication area, and fortunately, the ultimate goal of the NTN concept is the same. It is also worth studying the possibility that users who earnestly desire these environments may not insist on the complete form, but will incorporate new communication technologies from time to time. From this viewpoint, we hope to see continuing technological innovation in the future as well.

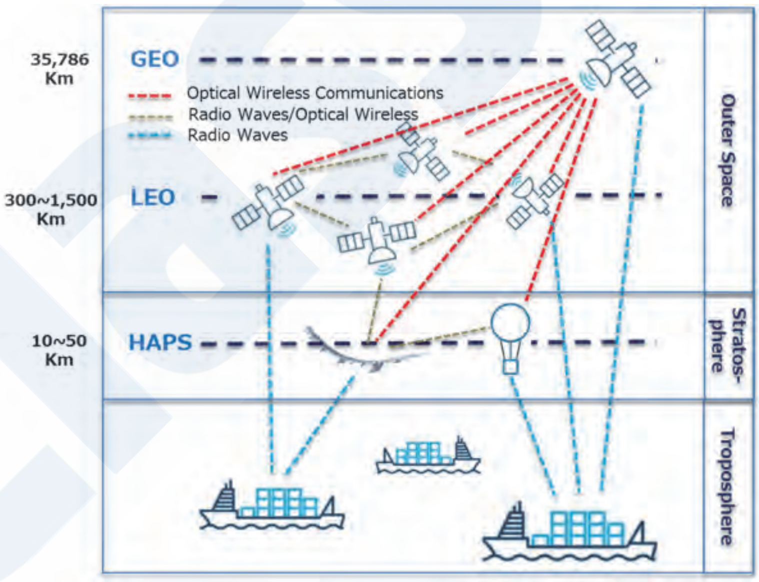

Fig. 3 Image of NTN environment

6. CONCLUSION

The commentary in this paper has been presented in order from the basics of telecommunications infrastructures to the most recent trends. If we consider the future form of communication infrastructure in the ship industry, the issues of aging seafarers and labor shortages are frequently mentioned, and as one measure that addresses these problems, the young generation particularly demands an internet environment that provides diverse kinds of connection. Against the backdrop of development and implementation of the communication environment on land, the market also demands initiatives that strengthen safe ship operation by sharing information concerning operation with the land side in real time, including shipping companies. Together with the global trend of digitalization, the wave of reform is also surging into the environment surrounding the ship industry, and IoT and automation of maneuvering and operation from remote location are driving reforms such as optimization of navigation routes and improvement of safety.

However, we realize that none of these improvements can be achieved without a stable communications infrastructure at sea. For example, if we turn our eyes to the global world, the general practice is online payment when paying utility bills or shopping, and all banks in the world are connected online, so the global economy will come to stop if the communication system goes down.

In the future, the author wishes to continue to convey the latest trends in telecommunications infrastructure to all those concerned, in order to be of assistance in the continuing development of the ship industry.

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Research and Development on Ship Collisions

— Consideration of the Equivalent Added Mass Coefficient of a Struck Ship [*1] —

Daisuke SHIOMITSU[*], Muneyuki KOKUDAI[**], and Tsutomu FUKUI[***]

1. INTRODUCTION

The Common Structural Rules of the International Association of Classification Societies (IACS) specify residual strength requirements for the accidental limit state of ships, considering loss of structural strength accompanying a collision or grounding, which require that a ship have sufficient hull strength to withstand waves and internal loads following a collision or grounding. Probabilistic risk assessments are necessary in the development and practical application of new concept ships loaded with new fuels such as hydrogen or ammonia, and evaluation of the collision/grounding resistance performance of ship fuel tanks and hull structures is important for this [1) 2)]. If an appropriate evaluation of collision/grounding resistance performance can be carried out, more rational design of the hull structure and flexible arrangement of the fuel tanks will become possible, while continuing to consider the risk of flooding and sinking and the risk of fuel leakage. Furthermore, when two ships collide, the scale of damage of the bow section of the striking ship and the hull of the struck ship varies depending on the ship motion accompanying the collision. Therefore, a coupled analysis of the ship motion (external dynamics) and the absorbed energy of the hull structure (internal mechanics) accompanying a collision is important for evaluating this phenomenon.

Several evaluation methods of this type of collision are available, but with recent progress in computer performance, Nonlinear Finite Element Analysis (NLFEA) is now generally used [3)]. In external dynamics, the effects of hydrodynamic forces (*e.g.*, added mass, *etc*.) associated with ship motion are frequently ignored or simplified to reduce the cost of the analysis. One simplification method is the Constant Added Mass Method (CAM method), in which a constant added mass is added to the ship's displacement mass and a whole ship collision and grounding analysis is carried out. Minorsky [4)] proposed an added mass coefficient of 0.4 for the sway motion of the struck ship during a collision. However, Motora *et al*. [5)] reported that the equivalent added mass coefficient of the struck ship (including the effect of the wave damping force) exceeds 0.4 as the duration of the collision becomes longer. In any case, rational and concrete values for the equivalent added mass coefficient which enable an appropriate evaluation of the effects of hydrodynamic forces (hydrodynamic effects) on the struck ship still have not been reported, and remain unclear.

Therefore, in this research, the authors examine an equivalent added mass coefficient which enables a proper evaluation of the hydrodynamic effects acting on a struck ship by analyzing the sway motion of the struck ship in a ship-ship collision of two fully-loaded VLCCs (Very Large Crude Carriers). If it is possible to derive an appropriate equivalent added mass coefficient for the struck ship, a simpler and more rational evaluation of collision resistance performance will become possible. The MCOL and S-ALE (Structured Arbitrary Lagrangian and Eulerian) fluid-structure interaction analysis methods packaged in the commercial NLFEA program LS-DYNA are used in this study.

2. OVERVIEW OF FLUID-STRUCTURE COUPLING METHODS FOR COLLISION ANALYSIS

2.1 MCOL

MCOL is a subprogram of LS-DYNA that can efficiently consider hydrodynamic effects in collision analyses by LS-DYNA [6)]. Concretely, it is possible to carry out collision analyses that consider the added mass, wave damping force (memory effect), restoring force (stability) and viscous force (drag) accompanying a collision. However, the added mass and wave damping

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coefficient must be calculated separately using an analysis program, *etc*. based on potential theory.

In MCOL, the following equation of motion is solved assuming that the ship's hull is a rigid body with 1 mass point and 6 degrees of freedom (6-DOF) [7].

$$\begin{aligned}&[M+M_A][\ddot{x}]+[G][\dot{x}]\\&=[F_W(\dot{x})]+[F_H(x)]+[F_V(\dot{x})]+[F_C]\end{aligned} \tag{1}$$

where, M and M_A are the displacement mass/inertia matrix of a ship and the added mass and inertia matrix for infinite frequency, respectively, G is the gyro matrix and F_W, F_H, F_V and F_C are the wave damping force (memory effect), restoring force, viscous force and contact force, respectively. In F_W, the memory effect is calculated by the following equation:

$$F_W=-\int_0^t [G(\tau)][\dot{x}(t-\tau)-\dot{x}(0)]d\tau \tag{2}$$

where,

$$G(\tau)=\frac{2}{\pi}\int_0^\infty [C(\omega)]\cos(\omega\tau)\,d\omega$$

$C(\omega)$ represents the wave damping coefficient matrix. The added mass/inertia matrix for infinite frequency and the wave damping coefficient matrix $C(\omega)$ in the frequency range of 0.02 to 2.38 rad/s (0.04 rad/s increments) were calculated using program of the 3-dimensional Green's function method. Because it is necessary to designate the values of the drag coefficient C_D in the viscous force term and, C_D = 0.8 (sway direction) was assumed in order to treat the VLCC [8].

2.2 S-ALE

The ALE method is a fluid-structure interaction analysis method, and is applicable to analyses of complex nonlinear phenomena such as collision analysis. To date, the ALE packaged in LS-DYNA has a proven record of use in research on ship collisions [9-11]. Recently, it has become possible to use the function called S-ALE, which achieved high efficiency in ALE. Due to the improved parallel performance of S-ALE, its computational speed is faster than that of the conventional ALE. S-ALE was used in this study. As in the conventional ALE, S-ALE models the structure and fluid by using Lagrangian elements and Eulerian elements, respectively.

Fig. 1 shows the models. Seawater and air were modeled as the fluids. Table 1 shows the values of the material properties (MAT) and equations of state (EOS) for seawater and air, which were decided referring to the literature [12]. Ambient elements were arranged over the full surface of the fluid, simulating an infinite domain field.

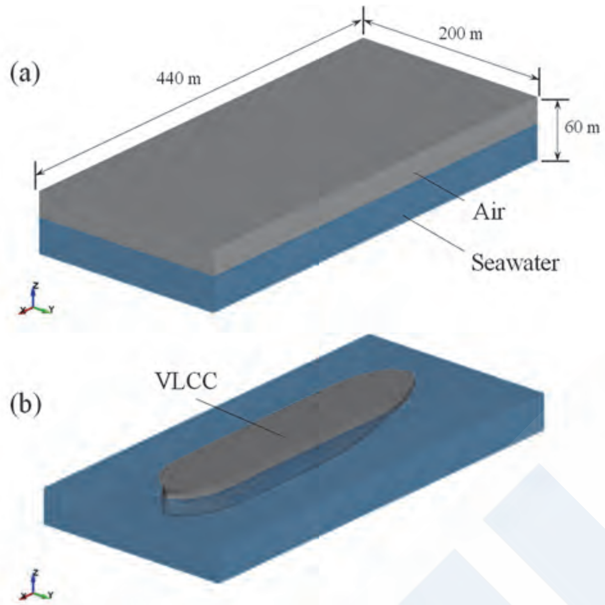


Fig. 1　FE-model for S-ALE: (a) dimensions of fluid domain; (b) VLCC which floats on fluid domain.

Table 1　Material properties for seawater and air.

Seawater		
*MAT NULL	Density, ρ (kg/m^3)	1025
	Pressure cutoff, P_c (Pa)	-100
	Viscosity coefficient, μ (Pa･s)	1.075×10^{-3}
*EOS GRUNEISEN	Nominal sound speed, C (m/s)	1500
	S1, S2, S3, GAMAO, A, E0	0.0
	V0 (-)	1.0
Air		
*MAT NULL	Density, ρ (kg/m^3)	1.1845
	Pressure cutoff, P_c (Pa)	-10
	Viscosity coefficient, μ (Pa･s)	1.850×10^{-5}
*EOS LINEAR POLYNOMIAL	C0, C1, C2, C3, C6	0.0
	C4, C5 (-)	0.4
	E0 (Pa)	2.533×10^{5}
	V0 (-)	1.0

2.3　Differences between MCOL and conventional ALE

Using MCOL and conventional ALE, Rudan *et al.* [11)] analyzed the sway velocity of an LPG ship in a collision by giving loads simulating the contact force during the accident to the ships, and compared the two methods. As a result, they reported that the sway velocity obtained by MCOL was larger than that by the conventional ALE. Drag calculations cannot be performed in a fluid analysis by the ALE in LS-DYNA, but drag can be considered easily by MCOL. Although this is a difference between the two programs, the actual reason for the difference between MCOL and ALE has not been clarified in detail. Therefore, we carried out a comparative verification by analyzing the sway velocity, contact force and absorbed energy of the struck ship

(VLCC) using the respective hydrodynamic effect evaluation methods (MCOL, S-ALE, and CAM method).

3. COLLISION ANALYSIS

3.1 Collision Scenario

As a dangerous collision scenario, a scenario in which the striking ship is as large or larger than the struck ship, and the kinetic energy of the striking ship is larger, is generally considered. Therefore, we assumed that the striking ship and the struck ship were identical, and both were in the fully-loaded condition. The principal particulars of the target ship (double-hulled VLCC) are shown in Table 2. The analysis conditions were set so that sway motion occurred in the struck ship, assuming that the centerline of the striking ship collides with the struck ship at right angles (90° angle) at its center of gravity position, as shown in Fig. 2. The speed of the striking ship was set to the 3 levels of 3, 6 or 9 knots, and the struck ship was in the stopped condition.

Table 2 Principal particulars of VLCC.

Dimensions	Value
Length, L_{oa} (m)	333
Length, L_{pp} (m)	324
Breadth, B (m)	60
Draft, d (m)	20.5
Displacement, Δ (ton)	3.418×10^5

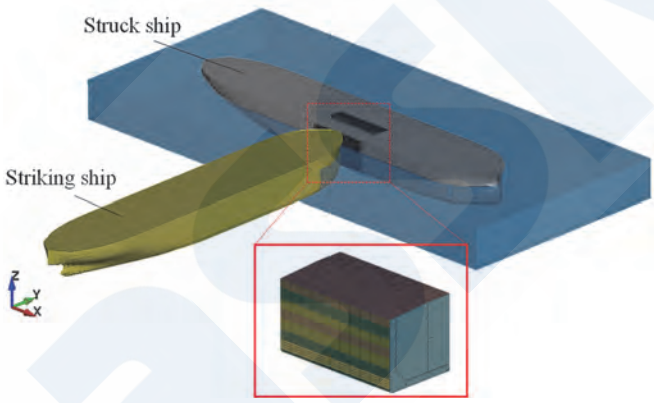


Fig. 2 FE-model for S-ALE between two ships in collision.

3.2 Analysis Model and Analysis Conditions

The NLFEA program LS-DYNA (ver. mpp d R12.0.0) was used in the analysis. Fig. 2 shows the FE model of the striking ship and struck ship when using S-ALE. The whole ship models (hull shape only) of the striking ship and the struck ship were both assumed to be rigid bodies (1 mass point, 6-DOF). The region around one longitudinal tank in the central part of the starboard side of the struck ship was modeled separately as an elastic-plastic body. The transverse bulkhead (rigid body) in the model of the ship's central starboard side was connected with the whole ship model (rigid body) by using *CONSTRAINED RIGID BODIES of LS-DYNA, which is used to connect pairs of rigid bodies, due to the analytical constraints on the fluid-structure interaction. Specifically, when using S-ALE, the sizes of the structural elements and the fluid elements must be substantially the same, but due to the extremely small element size of the elastic-plastic body (approximately 100 mm x 100 mm), use of fluid elements of the same small size would be impossible in terms of analysis cost. Therefore, the model of the central starboard side was connected to the whole ship model, in which a larger element size (approx. 4 m x 4 m) was applied, and only the whole ship model was coupled with the fluid elements, making it possible to conduct an efficient fluid-structure interaction analysis. Here, even though the elements of the whole ship model and the central starboard side model overlapped, a coupled evaluation of the external dynamics and internal mechanics in the collision analysis was possible by setting the model so that the bow of the striking ship only made contact with the struck ship's central starboard side model (and did not come into contact with the whole ship model). This approach has been used in conventional studies[10) 11)]. The analysis conditions of the striking ship and struck ship are summarized in Table 3. It may be noted that the element size of the whole ship model (approx. 4 m x 4 m) was determined by performing convergent calculations in S-ALE, while the element size of the ship's central starboard side (approx. 100 mm x 100 mm) was decided referring to the literature [13].

All members in the central starboard side model were prepared using shell elements (four-node Belytschko-Tsay elements). The total number of elements was approximately 2.64 million. Table 4 shows the material constants and other properties of the tank, which are based on the true stress-true strain curves. *MAT PIECE-WISE LINEAR PLASTICITY (024) of LS-DYNA was used as the material constitutive rule, and strain rate dependence was considered by using the Cowper-Symonds model. Rupture of the structure was expressed by removing elements when their equivalent plastic strain reached the critical failure strain shown in Table 4. The value of this failure strain was determined by referring to the past literature [13], considering the mesh size. The static/dynamic friction coefficients were set to 0.3. Because the purposes of this study were to carry out a relative comparison of the various hydrodynamic effect evaluation methods and study the equivalent added mass coefficient, the reader should note that simplified assumptions were used for the material constants, *etc*. of the elastic-plastic model described above.

Table 3 Analysis condition.

	Struck ship	Striking ship
Loading condition	Full	Full
Motion	6-DoF	Surge
Velocity (kt)	0.0	3.0, 6.0, 9.0
Hull (including bow)	Rigid	Rigid
Tank	Elasto-plastic	-
Coupling with fluid	Hull	-

Table 4 Material properties for the tank (true stress-strain) [13].

Steel grade	MS	HT32	HT36
Yield stress, σ_y (MPa)	235	315	355
Ultimate tensile stress, σ_u (MPa)	450	530	560
Critical failure strain, ε_{cr} (-)	0.20	0.167	0.15
Density, ρ (kg/m^3)	7850	7850	7850
Young's modulus, E (GPa)	206	206	206
Poisson's ratio, ν (-)	0.3	0.3	0.3
Tangent modulus, E_t (MPa)	1085	1303	1385
Strain rate parameter, C (-)	40.4	3200	3200
Strain rate parameter, P (-)	5.0	5.0	5.0

4. ANALYSIS RESULTS

4.1 Sway Velocity (Rigid Body)

As mentioned previously, it has been reported [11] that analyses by MCOL of LS-DYNA and the conventional ALE result in different sway velocity values. First, therefore, the sway velocity of only the whole ship model (rigid body, 1 mass point, 6-DOF) was analyzed using each of the hydrodynamic effect evaluation methods (MCOL, S-ALE CAM method), and the obtained results were analyzed. The target ships were moved by applying a load simulating the contact force during a collision (sine wave, duration of action: 5 s), as shown in Fig. 3, at the center of gravity of the struck ship in the sway direction. This load simulates the contact force obtained in the collision analysis when the forward (surge) velocity of the striking ship was 6 kt.

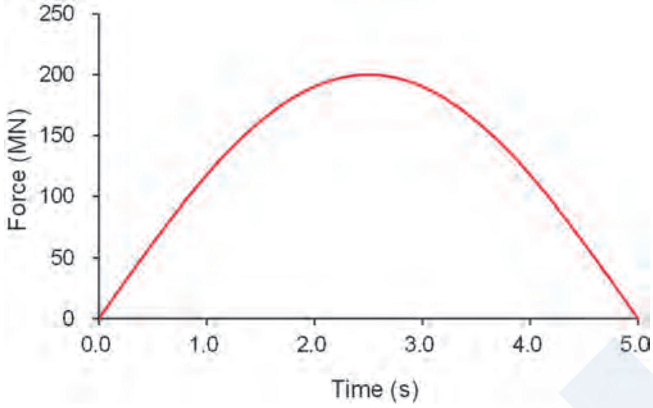


Fig. 3　Force assumed in sine wave similar to contact force during collision.

Fig. 4 shows the result of a comparison of the sway velocities obtained by each of the hydrodynamic effect evaluation methods. Good agreement between the results of the MCOL and S-ALE methods can be confirmed. Although it had been reported that the results by these two methods in the conventional study were not in agreement, the results were almost identical. Although the reason for the reported difference has not been clarified, it can be inferred that a difference in the ship types, *etc.* in the conventional study and this study was a factor. In addition, as noted previously, calculations for drag are not possible by the ALE of LS-DYNA (including S-ALE), but drag can be considered easily by MCOL. However, the difference between S-ALE and MCOL in this analysis is thought to have little effect on the sway velocity (as discussed in detail later).

Next, when using the CAM method, a decrease in the sway velocity can be observed as the equivalent added mass coefficient increases. This is a natural result of the increase in the displacement mass as the equivalent added mass coefficient becomes larger. The CAM results calculated with the equivalent added mass coefficient of 0.4 are in agreement with the MCOL results and S-ALE results until around 3 seconds. Although Motora *et al.* [5)] reported that the hydrodynamic effects can be evaluated by using an equivalent added mass coefficient of 0.4 when the duration of the collision is short, the trend is similar to their results. However, as the elapsed time increases, the velocities obtained by the MCOL and S-ALE methods decrease, while the results obtained by the CAM method converge on constant values for each of the equivalent added mass coefficients used in the analysis. This difference occurs because the effect of the wave damping force (memory effect) with temporal change is considered in MCOL and S-ALE, whereas in the CAM method, the damping effect is considered as a constant value which is included in the equivalent added mass coefficient. Fig. 5 presents results supporting this conclusion.

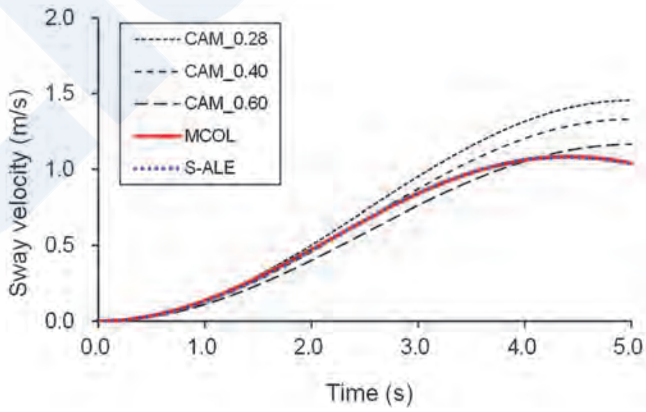


Fig. 4　Sway velocity of VLCC obtained by FEA with MCOL, S-ALE, and CAM. Equivalent added mass coefficients in CAM are 0.28 (infinite frequency), 0.40, and 0.60.

Fig. 5 shows the sway velocity in case all the hydrodynamic forces (added mass, wave damping force (memory effect), restoring force (stability), viscous force (drag)) are considered in the MCOL analysis, together with the sway velocity when each of the respective forces is not considered. The effects of restoring force (stability) and viscous force (drag) are extremely small. The effect of the wave damping force (memory effect) increases with elapsed time. Therefore, the sway velocity obtained by the CAM method, which uses an equivalent added mass coefficient, diverges from the results of MCOL and S-ALE with the passage of time. It is considered necessary to investigate the degree of effect that this difference has on the absorbed energy of the struck ship during a collision. The results of that investigation are presented in the following section.

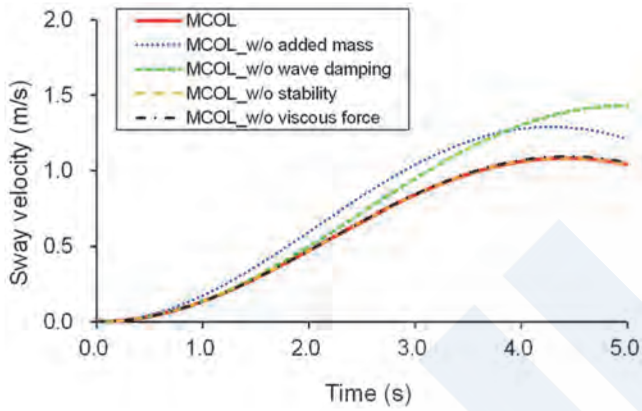


Fig. 5 Hydrodynamics effects on sway velocity of VLCC obtained by FEA with MCOL.

4.2 Sway Velocity, Contact Force and Absorbed Energy (Elastic-Plastic Body)

The ship central starboard side model (elastic-plastic body) was connected to the whole ship model (rigid body, 1 mass point, 6-DOF), and whole ship collision analyses were carried out using each of the hydrodynamic effects evaluation methods (MCOL, S-ALE, and CAM method). However, the hydrodynamic effects were considered only for the struck ship. Because the motion of the striking ship is limited to surge motion, coupling with the fluid is not considered. Since the focus of this research is to study the equivalent added mass coefficient of the struck ship, the hydrodynamic effects acting on the striking ship are an issue for future work.

Fig. 6 shows the condition at the final time of the simulation by S-ALE for the case where the surge velocity of the striking ship is 6 kt. Disturbance of the free (fluid) surface can be confirmed from the figure.

Fig. 7 shows the condition of damage (deformation and equivalent plastic strain distribution) of the elastic-plastic portion of the struck ship at the final time of the analysis with S-ALE when the surge velocity of the striking ship is 3 kt, 6 kt or 9 kt. The deformation of the struck ship increases as the surge velocity of the striking ship becomes larger. However, the reader should note that the bow section of the striking ship is treated as a rigid body, which means the deformation and damage that occur in the struck ship under the various collision scenarios are overestimated, in comparison with the case where the striking ship is modeled as an elastic-plastic body.

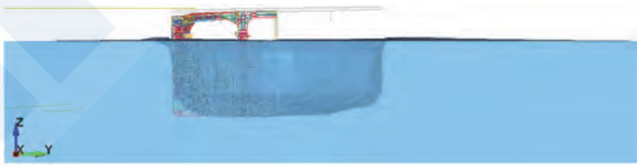
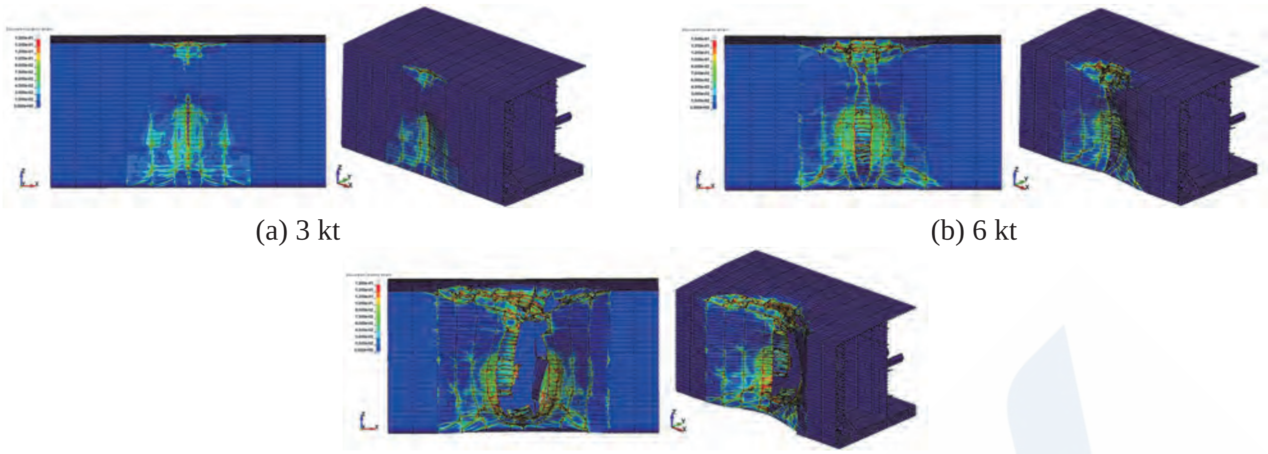


Fig. 6 Sway motion of the struck ship and disturbed fluid surface obtained by NLFEA with S-ALE at final time of simulation. Surge velocity of the striking ship is 6 kt.



(a) 3 kt

(b) 6 kt

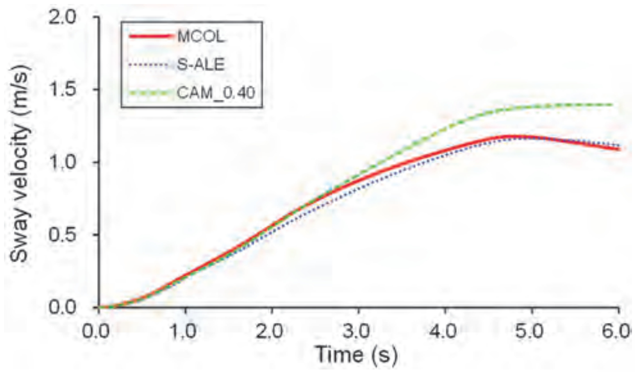
(c) 9 kt

Fig. 7 Structural damage (deformation and equivalent plastic strain) of the struck ship obtained by NLFEA with S-ALE at final time of simulation. Surge velocity of the striking ship: (a) 3 kt; (b) 6 kt; and (c) 9 kt.

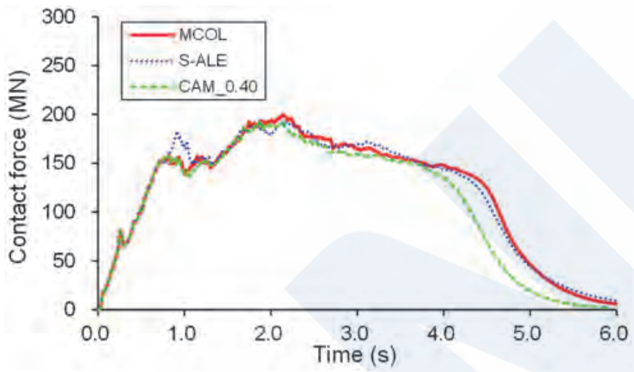
Fig. 8(a) shows a comparison of the sway velocity of the struck ship obtained by each of the hydrodynamic effects evaluation methods for the case where the surge velocity of the striking ship is 6 kt. Good agreement between the sway velocities obtained by MCOL and S-ALE can be confirmed from this figure. As in the case of the whole ship model without an elastic-plastic section described previously, almost identical results could be obtained by MCOL and S-ALE in the collision analysis including an elastic-plastic section. However, when the CAM method was used (equivalent added mass coefficient: 0.4), the sway velocity was similar to that given by MCOL and S-ALE until a collision duration of around 3 seconds, but became larger than the results by MCOL and S-ALE after that time. As discussed above, this divergence occurs because the CAM method treats the wave damping effect as a constant value.

Fig. 8(b) shows the time history of contact force. In this figure, the contact force history is almost the same by all the hydrodynamic effects evaluation methods until approximately 4 seconds, but the tendency of the S-ALE results differs from those of the other methods at around 1 second. This deviation occurs because only the S-ALE analysis considers the force of gravity. That is, the effect of gravity causes a slight upward displacement of the struck ship, and this changes the contact position with the striking ship. To support this conclusion, we conducted a separate S-ALE analysis in which the displacement of the struck ship in the height direction was constrained, and confirmed that the contact force history was the same as those obtained by the other hydrodynamic effects evaluation methods (MCOL and CAM method). Limited to the CAM method analysis, the contact force decreased after 4 seconds. This is because the sway velocity of the struck ship obtained by the CAM method exceeds the results of the MCOL and S-ALE after a certain time, as discussed previously.

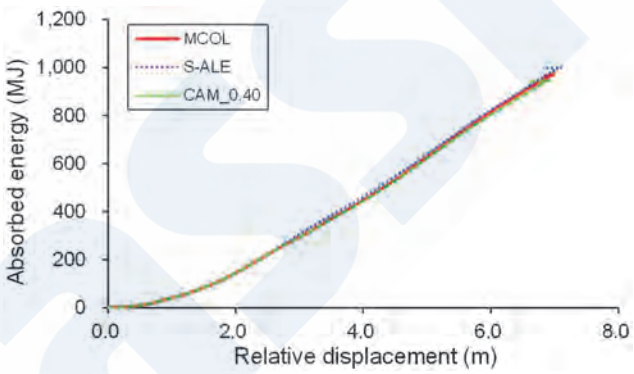
Fig. 8(c) shows absorbed energy, which was calculated by integrating the obtained contact force by the amount of penetration into the struck ship (in this research, this is treated as the relative displacement of the two vessels). Indexed to 1.00 by the CAM method (equivalent added mass coefficient: 0.4), the absorbed energy at the end of the collision (defined as the time when the velocities of the striking ship and struck ship become equal), was 1.02 by MCOL and 1.05 by S-ALE. Satisfactory agreement was obtained between the MCOL and S-ALE results, as the difference between the two was approximately 3%. On the other hand, when the surge velocity of the striking ship is 6 kt, these results showed that the CAM method (equivalent added mass coefficient: 0.4) estimates collision resistance performance slightly to the unsafe side.



(a) Sway velocity



(b) Contact force



(c) Absorbed energy

Fig. 8 Sway velocity, contact force, and absorbed energy obtained by NLFEA with MCOL, S-ALE and CAM (Equivalent added mass coefficient is 0.4). Surge velocity of the striking ship is 6 kt.

Finally, the CPU time (8CPU, MPP) required for collision analyses by each of the hydrodynamic effects evaluation methods discussed above was approximately 110 hours for the CAM method and MCOL, and approximately 120 hours for S-ALE. Since there is almost no difference between the CAM method and MCOL, it can be said that fluid-structure interaction analyses can be performed by MCOL without incurring a higher analysis cost. Moreover, although the longer analysis time required with S-ALE is considered a demerit, since the increase is limited to about 10 hours in comparison with the other methods, it was found that S-ALE can be used without problems under the analysis conditions of this study.

4.3 Calculation of Equivalent Added Mass Coefficient Using Analytical Solution

In order to evaluate the equivalent added mass coefficient from the absorbed energy obtained in the collision analyses by MCOL and S-ALE, the law of conservation of momentum and kinetic energy loss $\triangle E_k$ are considered. Assuming that the striking ship collides with the struck ship at right angles at the center of gravity position of the struck ship, the law of conservation of momentum is expressed by the following equation.

$$m_1(1 + A_1)v_1 = [m_1(1 + A_1) + m_2(1 + A_2)]v_c \tag{3}$$

where, m_1 and m_2 are the displacement mass of the striking ship and the struck ship, A_1 and A_2 are the equivalent added mass coefficient of the striking ship and the struck ship, v_1 is the surge velocity of the striking ship, and v_c is the common velocity of the striking ship and the struck ship at the end of the collision. The kinetic energy loss $\triangle E_k$ at the end of the collision is expressed by the Eq. (4).

$$\Delta E_k = \frac{1}{2} m_1 (1 + A_1) v_1^2 - \frac{1}{2} [m_1(1 + A_1) + m_2(1 + A_2)] v_c^2 \quad (4)$$

The following equation can be derived by transforming Eq. (3) for the common velocity v_c and substituting the result into Eq. (4).

$$\Delta E_k = \frac{1}{2} \frac{m_1(1 + A_1) m_2(1 + A_2)}{m_1(1 + A_1) + m_2(1 + A_2)} v_1^2 \quad (5)$$

Eq. (5) was derived according to Minorsky [4]. Because the striking ship and struck ship in this study are the same type of ship, the displacement mass $m_1 = m_2$, and because the equivalent added mass coefficient of the striking ship is not considered, $A_1 = 0$. When these values are substituted into Eq. (5), Eq. (6) is obtained.

$$\Delta E_k = \frac{1}{2} \left(\frac{1 + A_2}{2 + A_2} \right) m_1 v_1^2 \quad (6)$$

As a result, the kinetic energy loss $\triangle E_k$ is expressed by the initial kinetic energy of the striking ship, $m_1 v_1^2 / 2$ and the equivalent added mass coefficient A_2 of the struck ship.

First, analytical accuracy was verified by comparing the calculated $\triangle E_k$ in Eq. (6) and the kinetic energy loss obtained by NLFEA using the CAM method (equivalent added mass coefficient: 0.4). Here, because the kinetic energy loss comprises the absorbed energy of the contact (frictional) energy and the internal energy of the struck ship at the end of the collision, the absorbed energy at the end of the collision by the CAM method (maximum value in Fig. 8(c)) and the value calculated by Eq. (6) were compared. In case the surge velocity of the striking ship is 6 kt, the values of absorbed energy obtained by the CAM method and the value of $\triangle E_k$ calculated by Eq. (6) were 948 MJ and 950 MJ, respectively, showing good agreement with an error of only 0.2%. As a result, the collision analysis results are valid. In the following, the value obtained by Eq. (6) will be treated as equal to the value obtained by the NLFEA using the CAM method. The NLFEA using the CAM method was carried out only for the case where the surge velocity of the striking ship is 6 kt. Table 5 shows the absorbed energies obtained by NLFEA using MCOL and S-ALE when the surge velocities of the striking ship are changed. The absorbed energies were nondimensionalized by division by the value calculated by Eq. (6) (equivalent added mass coefficient: 0.4). First, comparing the results by MCOL and S-ALE, the difference was on the order of 3%, even when the surge velocity of the striking ship was changed, confirming that almost the same results can be obtained by the two methods. It can be confirmed that the results calculated by Eq. (6) (equivalent added mass coefficient: 0.4) showed that this method estimates collision resistance performance approximately up to 8% to the unsafe side. It may be not appropriate to treat the equivalent added mass coefficient as a uniform value of 0.4 regardless of changes in the surge velocity, *etc*. of the striking ship.

Fig. 9 shows the absorbed energy obtained by MCOL and S-ALE for the initial kinetic energy of the striking ship, $m_1 v_1^2 / 2$. This figure indicates that the initial kinetic energy of the striking ship and the absorbed energy of the struck ship exist in a proportional relationship. This can also be confirmed from Eq. (6). In addition, by taking the slopes obtained from the approximate lines of the results of MCOL and S-ALE, and assuming they are equal to the equivalent added mass coefficient term on the right side of Eq. (6), i.e., $(1 + A_2) / (2 + A_2)$, it is possible to find the equivalent added mass coefficient calculated backward from the MCOL and S-ALE results. As a result, the equivalent added mass coefficient calculated backward from the MCOL results was 0.57, while that for S-ALE was 0.68, confirming that the values by these methods are significantly larger than the equivalent added mass coefficient of 0.4 which is used conventionally. This is consistent with the report by Motora *et al.*, as described in the Introduction. Here, there is a difference of approximately 20% between the equivalent added mass coefficients of 0.57 and 0.68 obtained by MCOL and S-ALE, respectively, but because the difference in the results for absorbed energy by these two methods was limited to about 3%, the effect of changes in the equivalent added mass coefficient on changes in absorbed energy is slight. Accordingly, when evaluating the absorbed energy of a target ship until the end of a collision, it is thought that collision resistance performance can be evaluated rationally and conservatively by setting the equivalent added mass coefficient at, for example, 0.7.

Table 5 Energy of the struck ship obtained by NLFEA with MCOL and S-ALE.

Surge velocity of striking ship (kt)	Energy* (MCOL/Eq. (6))	Energy* (S-ALE/Eq. (6))
3.0	0.99	1.04
6.0	1.02	1.05
9.0	1.05	1.08

*Note: Energy represents the value of absorbed energy obtained by NLFEA with MCOL or S-ALE divided by Eq. (6) with equivalent added mass coefficient 0.4.

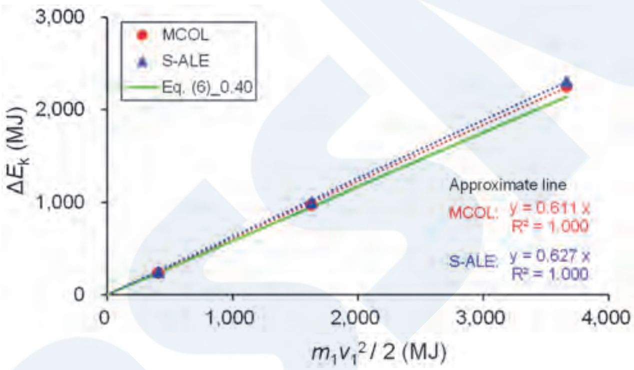


Fig. 9 ΔE_k obtained by NLFEA with MCOL and S-ALE.

5. CONCLUSION

A fluid-structure interaction analysis by MCOL and S-ALE was carried out for a ship-ship collision of two fully-loaded double-hulled VLCC using the commercial NLFEA program LS-DYNA in order to study the equivalent added mass coefficient for the sway motion of the struck ship. By deriving an appropriate equivalent added mass coefficient for the struck ship, a simpler and more rational evaluation of absorbed energy is possible. The knowledge obtained in this study is summarized below.

(1) It is possible to obtain substantially identical results in a sway velocity evaluation of a struck ship by MCOL and S-ALE, which can be used in LS-DYNA.

(2) If the absorbed energy of the struck ship at the end of the collision is evaluated using the conventional equivalent added mass coefficient of 0.4, an absorbed energy value smaller than those obtained by MCOL or S-ALE may be estimated, depending on the surge velocity of the striking ship, suggesting the possibility that the collision resistance performance of the ship may be estimated on the unsafe side.

(3) Since the effect of changes in the equivalent added mass coefficient on changes in absorbed energy is slight, it is appropriate, for a rational and conservative evaluation of collision resistance performance, to set an equivalent added mass coefficient on the order of 0.7 when evaluating the sway velocity of the struck ship.

Because this study only considered a double-hulled VLCC as the struck ship, collision analyses of different ship types, *etc.* may be mentioned as an issue for future work.

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Recent Topics at IMO

— Outline of Discussion at IMO Committees —

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1. INTRODUCTION

This article introduces recent topics discussed at International Maritime Organization (IMO). At the previous issue, a summary of the topics discussed at 79th Marine Environment Protection Committee (MEPC 79) held in December 2022 and 106th Maritime Safety Committee (MSC 106) held in November 2022 was provided.

This article provides a summary of the decisions taken at 80th Marine Environment Protection Committee (MEPC 80) held from 3 to 7 July 2023 and 107th Maritime Safety Committee (MSC 107) held from 31 May to 9 June 2023 as below. Refer to the separate article “Recent Topics on GHG Emissions Reduction from International Shipping” for those topics related to Greenhouse Gases (GHG) discussed at MEPC 80 not covered by this article.

2. OUTCOMES OF MEPC 80

2.1 Greenhouse Gases (GHG)

2.1.1 Review of Data Collection System for Fuel Oil Consumption of Ships

The Data Collection System for fuel oil consumption of ships (DCS), under which operational data such as fuel oil consumption has been collected and reported since 2019, has been under review since 2022 to improve the items to be reported and the granularity of reported data.

At this session, draft amendments to MARPOL Annex VI Appendix IX were approved, including the amendments and additions to the following items required to be reported in the DCS.

1. Fuel oil consumption per combustion systems (main engines, auxiliary engines/generators and oil-fired boilers);
2. Fuel oil consumption while the ship is not under way;
3. Laden distance traveled (on a voluntary basis);
4. Transport work;
5. Total amount of on-shore power supplied; and
6. Category of Innovative energy efficiency technologies.

The amendments will be adopted at MEPC 81. It is also noted that the “transport work” above was agreed to be calculated based on the actual amount of cargo, the details of which will be further discussed at MEPC 81 along with amendments to the relevant guidelines.

2.1.2 Use of Power Reserve in EEDI Regulations

At the previous session, it was agreed in general to introduce the concept of the use of power reserve, which is limited under normal operations, during emergency situations (i.e. in adverse conditions) in order to conform with both the Energy Efficiency Design Index (EEDI) and minimum propulsion power regulations.

At this session, discussions were held with an aim to introduce the concept, particularly regarding the definition of power of main engines (P_{ME}), referred maximum continuous rating (MCR) in NOx certification framework and possible implications on the NOx Technical Code. Specifically, divergent views were expressed from delegations towards whether the definition of P_{ME} should be based on 75% of limited MCR (MCR_{lim}) as referred to in the EEDI regulations, or the lower value between 83% of MCR_{lim} or 75% of MCR. The discussions will be continued in future sessions as agreements could not be reached at this session.

2.1.3 Onboard Carbon Capture Systems

There have been initiatives to develop onboard carbon capture (OCC) technologies for reducing GHG emissions by segregating and capturing CO2 from exhaust gases onboard ships. At the last session, a proposal was made that the amount of CO2 captured by OCC Systems should be taken into consideration when calculating the attained EEDI, Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII).

At this session, a new output under Intersessional Working Group on Reduction of GHG from Ships (ISWG-GHG) was agreed for further work to develop a regulatory framework to allow for uses of OCC technologies.

2.2 BWM Convention

2.2.1 Review of BWM Convention

When BWM Convention entered into force in 2017, it was agreed to monitor the application and to review the effectiveness of the Convention through the experience building phase (EBP), in which a relevant Correspondence Group was established to develop and prepare a Convention Review Plan (CRP).

At this session, MEPC approved the CRP that includes the issues to be finalized. Furthermore, a Correspondence Group was re-established to continue with the review of the BWM Convention by MEPC 81. Amendments to the BWM Convention are currently planned to be approved at MEPC 84 (spring 2026) and to be adopted at MEPC 85 (autumn 2026).

2.2.2 Ballast Water Management in Ships Operating in Challenging Water Quality and Temporary Storage of Treated Sewage and/or Grey Water

As there are ports with challenging water quality (CWQ) that make it difficult to continuously operate ballast water management systems (BWMS), a draft interim guidance has been proposed to allow taking in ballast water while bypassing BWMS in such ports and employing ballast water exchange plus treatment (BWE + BWT) at areas where the treatment system can operate normally. At this session, comments were raised regarding the timing when such bypassing should be commenced and when normal operation should be resumed. However, no general agreement could be reached and therefore the discussion will be continued at MEPC 81.

In addition, the prohibition on the discharge of treated sewage and grey water at certain ports has led to temporary storage of treated sewage and grey water in ballast tanks, and thus another draft guidance has been proposed to set out measures to be taken when treated sewage and/or grey water should be temporarily stored into ballast tanks at such ports. Discussions were held regarding several guidance proposals at this session, but due to time constraints, it was concluded that the discussion will continue at MEPC 81 following intersessional work to develop a concrete proposal.

2.2.3 Protocol for Verification of Ballast Water Compliance Monitoring Devices

The BWM Convention regulates the number of organisms per volume in treated ballast water. To verify compliance to the regulation, ballast water compliance monitoring devices (CMD) have been used as a rapid assessment of the concentration of viable organisms in treated water. In this regard, a framework for the verification of the performance of ballast water CMD has been discussed at the Sub-Committee on Pollution Prevention and Response (PPR).

At this session, the Protocol for Verification of Ballast Water Compliance Monitoring Devices developed by PPR was approved. The CMD approved in accordance with the protocol are expected to be utilized at scenes such as PSC sampling and onboard monitoring.

2.2.4 Unified Interpretation on the Format of BWM Certificate

The unified interpretation drafted at PPR was approved at this session, addressing the application of the BWM Certificate in terms of the date of construction for ships that went under a major conversion.

2.2.5 Guidance on BWRB

In relation to the amendments to the mandatory requirement regarding the format of Ballast Water Record Books (BWRB) being adopted at this session, the guidance on matters relating to ballast water record-keeping and reporting was approved. In addition, the guidelines for the use of electronic record books under the BWM Convention were adopted along with the approval of consequential amendments to the Regulations A-1 and B-2 of the BWM Convention, the latter of which will be adopted at MEPC 81.

2.3. Air Pollution

2.3.1 Revision of the Requirements of Bunker Delivery Note for Low-Flashpoint Fuels and Gas Fuels

At the previous session, amendments to MARPOL Annex VI were adopted to include flashpoint information of the fuel delivered to the ship into the bunker delivery note (BDN). Meanwhile, further discussions were held to clarify the application of BDN requirements to low-flashpoint fuels and gas fuels.

At this session, amendments to MARPOL Annex VI have been approved, which clarify the requirements for onboard storage and minimum information of BDN for low-flashpoint fuels and gas fuels. These amendments will be adopted at MEPC 81.

2.4 Others

2.4.1 Minimization of Transfer of Invasive Aquatic Species

Since 2020, the 2011 Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species (Res. MEPC.207(62)) have been reviewed in terms of their practicalities and effectiveness.

At this session, amendments to the Guidelines were adopted, which include the provisions on hull inspection frequency on the basis of the anti-fouling system (AFS) application, recommended cleaning on the basis of the results from hull inspections, etc. It was also agreed that guidelines on matters relating to provisions on capture rates of biomass and particles during in-water cleaning will be developed by 2025.

2.4.2 Amendments to Guidelines for the Development of the Inventory of Hazardous Materials

With respect to the restriction of the use of cybutryne as anti-fouling system since January 2023, amendments to the Guidelines for the Development of the Inventory of Hazardous Materials (Res. MEPC.269(68)) have been adopted, adding cybutryne to hazardous materials to be listed in the Inventory of Hazardous Materials (IHM), the development of which is required in the Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, 2009 (also known as the Ship Recycling Convention or the Hong Kong Convention).

2.5 Amendments to Mandatory Instruments

2.5.1 Amendments to the Format of Ballast Water Record Book

Amendments to the format of Ballast Water Record Books (BWRB) in the BWM Convention Appendix II were adopted, which require recording in terms of Codes (letter) and Items (number) similar to the format of Oil Record Books, instead of specifying records in Items (number) only. The amendments will enter into force on 1 February 2025.

3. OUTCOMES OF MSC 107

3.1 Adopted Mandatory Requirements

Mandatory requirements were adopted at MSC 107 as follows:

(1) Amendments to SOLAS Chapter II-1 on safety requirements for lifting appliances and anchor handling winches

Amendments to SOLAS chapter II-1 to provide safety requirements on lifting appliances and anchor handling winches were adopted. Accordingly, thorough examination and load test in compliance with the guidelines introduced in item 3.3.2(1) would be required for those equipment installed to new and existing ships.

(2) Amendments to SOLAS chapter II-2, etc. on the prohibition of perfluorooctane sulfonic acid (PFOS)

Amendments to SOLAS chapter II-2, and the 1994 and 2000 HSC Codes to prohibit the use of fire-fighting foams containing PFOS, were adopted.

(3) Amendments to SOLAS chapter V and format of SE Certificate on carriage of electronic inclinometers

Amendments to SOLAS chapter V to require carriage of electronic inclinometers on container ships and bulk carriers of 3,000 gross tonnage and upwards were adopted. Accordingly, format of SE Certificate was also amended to add new entry of "Container ship" in Particulars of ship. The requirement would be applied to new bulk carriers defined under SOLAS XII and ships which are intended primarily to carry containers.

(4) Amendments to LSA Code

Amendments to LSA Code to add new ventilation requirements applied to totally enclosed lifeboats, in conjunction with the amendments to the recommendation on testing of life-saving appliances (resolution MSC.81(70)) which newly stipulates the relevant operation tests, were adopted.

(5) Amendments to IMSBC Code

The 7th amendments to IMSBC Code (AMENDMENT 07-23) were adopted, including addition of new cargoes.

3.2 Approved Mandatory Requirements

The following mandatory requirements were approved at this session, and are expected to be considered for adoption at MSC 108 in May 2024.

(1) Amendments to IGF Code

Amendments to IGF Code were approved as a part of the task for amendments to the IGF Code and development of guidelines for alternative fuels and related technologies. It was also agreed to issue an MSC circular on the early implementation of the draft amendments to paragraphs 4.2.2 and 8.4.1 to 8.4.3 of the Code.

(2) Amendments to International Code for the Safe Carriage of Grain in Bulk (Grain Code) (resolution MSC.23(59))

Amendments to Grain Code, to add new loading condition of specially suitable compartments partly filled in way of the hatch opening with ends untrimmed, were approved.

(3) Amendments to SOLAS regulation II-1/3-4

Amendments to SOLAS regulation II-1/3-4 to require emergency towing arrangements fitted on ships other than tankers of not less than 20,000GT were approved. The detailed requirements would be considered based on the existing guidelines (Res. MSC.35(63)) at SDC Sub-Committee.

(4) Amendments to LSA Code

The following amendments to LSA Code and the *recommendation on testing of life-saving appliances* (resolution MSC.81(70)) were approved;

1. In-water performance requirements for lifejackets;
2. Requirements for single fall and hook systems with on-load release capability which is used for lifeboat launched by a fall or falls, except a free-fall lifeboat; and
3. Requirements for lifeboats to limit the minimum and maximum lowering speed of fully loaded survival craft and rescue boats.

(5) Amendments to SOLAS chapter II-2 and FSS Code

The following amendments to SOLAS chapter II-2 and FSS Code on fire safety of ro-ro passenger ships, etc. were approved;

1. Fire safety requirements on new/existing ro-ro passenger ships mainly shown as below;
   - Fixed fire detection and fire alarm systems including linear heat detectors;
   - Video monitoring in ro-ro spaces;
   - Arrangement of openings in ro-ro and special category spaces;
   - Arrangement of weather decks; and
   - Water monitors for protection of weather deck
2. Amendments to SOLAS regulation II-2/7.5.5 to require fixed fire detection and fire alarm systems within control stations and cargo control rooms in addition to accommodation spaces of cargo ships.

3.3 Approval of Unified Interpretations (UIs), Guidelines and Guidance etc.

The following unified interpretations (UIs), guidelines, guidance and etc. were approved during MSC 107. IACS UI referred to as below is available on IACS website (http://www.iacs.org.uk/).

3.3.1 UIs

(1) Unified interpretation of IGF Code

1. Unified interpretation of 5.8 to clarify applicability of requirements on arrangements and bilge well of fuel preparation rooms not located on open deck.
2. Unified interpretation of 9.2.2 to restrict the use of single common flange in the piping system for fuel transfer to the consumers.

(2) Unified interpretation of IGC Code

1. Unified interpretation to clarify that cargo transfer equipment installed on LNG bunkering ships should comply with 11.3.1.4, 11.3.1.5, 11.4.1, 11.4.3 and 18.10.3.2 for fire detection and fire protection in the cargo area.
2. Unified interpretation on the conduct of verifications and examinations required during the first full loading and unloading of the cargo under 4.20.3.5, 4.20.3.6, 4.20.3.7, 5.13.2.5 and 13.3.5.

(3) Amendments to unified interpretation of 2008 IS Code (MSC.1/Circ.1537/Rev.1)

Amendments to unified interpretation of 2008 IS Code (MSC.1/Circ.1537/Rev.1) to make specific down-flooding points (ventilators fitted with weathertight closing appliances, serving at machinery spaces that are required to remain open, are regarded as unprotected openings), which were formerly applied only to weather criterion, applied to the entirety of the 2008 IS Code.

(4) Amendments to unified interpretation of SOLAS chapter II-1 (MSC.1/Circ.1362/Rev.1)

Amendments to unified interpretation of SOLAS chapter II-1 (MSC.1/Circ.1362/Rev.1) to include the following new interpretations.

1. Unified interpretation of regulation II-1/3-8 on mooring arrangement and equipment to clarify the documentation which was necessary to support an Administration or an RO in verifying compliance with regulation II-1/3-8; and
2. Unified interpretation of regulation II-1/13.2.3 to provide clarification for pressure testing of penetrations in watertight divisions after a fire test for passenger ships.

(5) Unified interpretation of LSA Code and 1994/2000 HSC Code

Unified interpretation of LSA Code and 1994/2000 HSC Code to accept multiple light source LED torch as an alternative to “one spare bulb” equipped for liferaft, lifeboat and rescue boat, provided that the failure of any one of LED does not prevent the fully functioning of other LEDs.

(6) Amendments to unified interpretation of SOLAS chapter II-2 (MSC.1/Circ.1276)

Amendments to unified interpretation (MSC.1/Circ.1276) in line with the application to the generalized “ducts”, not only to galley ducts in SOLAS regulation II-2/9.7.2.5. The amended interpretation applies to fire protection construction, installation, arrangements and equipment to be installed on board ships of which the building contract is placed on or after the date of approval.

3.3.2 Guidelines and Guidance etc.

(1) Guidelines on lifting appliances and anchor handling winches

In conjunction with the amendments to SOLAS as shown in above 3.1(1), the relevant two (2) guidelines on lifting appliances and anchor handling winches were approved.

(2) Interim guidelines for the safety of ships using LPG fuels

Interim guidelines for the safety of ships using LPG fuels, as a part of the task for amendments to the IGF Code and development of guidelines for alternative fuels and related technologies.

(3) Interim guidelines on onshore power supply (OPS)

Interim guidelines on safe operation of onshore power supply (OPS) service in port for ships engaged on international voyages.

(4) Amendments to performance standards for water level detectors on ships subject to SOLAS regulations II-1/25, II-1/25-1 and XII/12 (resolution MSC.188(79)/Rev.1)

Amendments to performance standards for water level detectors on ships subject to SOLAS regulations II-1/25, II-1/25-1 and XII/12 (resolution MSC.188(79)/Rev.1) to clarify that the measurement of height from the bottom of a bilge well is applied to bilge level sensors in regulation II-1/25-1.3.

(5) Amendments to Hazardous area classification (application of SOLAS regulation II-1/45.11) (MSC.1/Circ.1557)

Amendments to Hazardous area classification (application of SOLAS regulation II-1/45.11) (MSC.1/Circ.1557) in order to address inconsistencies between the standard IEC 60092-502. (related to IACS UI SC274)

3.4 Postponement of Application of a Part of Performance Standard of GMDSS Equipment in Relation to Resolutions MSC.511(105), MSC.512(105) and MSC.513(105)

As modernization of the Global Maritime Distress and Safety System (GMDSS), the relevant performance standards, guidelines and guidance have been approved at MSC 105 with entry into force on 1 January 2024.

However, noting the relevant new IEC standards are not yet developed, concerns were expressed that shipborne VHF, MF and MF/HF radio installations and Inmarsat-C ship earth stations meeting the new performance standards approved at MSC 105 may not be supplied by the effective date.

To address this situation, MSC 107 agreed to permit continued installation of radio installations that comply with the existing standards (i.e. resolutions A.803(19), as amended, A.804(19), as amended, A.806(19), as amended and A.807(19), as amended) until 1 January 2028.

Accordingly, MSC circular on *Delays affecting the availability of new GMDSS equipment compliant with the revised performance standards*, set out in resolutions MSC.511(105), MSC.512(105) and MSC.513(105) and the revision of MSC.1/Circ.1460/Rev.3 on *Guidance on the validity of radiocommunications equipment installed and used on ships* were approved at this session.

3.5 Consideration of Requirements for Maritime Autonomous Surface Ships (MASS)

In the recent development of MASS, it has been discussed at MSC on an international instrument of MASS (MASS Code).

At this session, based on the report by the Correspondence Group (CG) and the meeting outcome arranged by the related working group such as the second Joint MSC-LEG-FAL Working Group (JWG2), non-mandatory MASS Code has been discussed and agreed on further consideration. In addition, the road map for developing the MASS Code was discussed, which resulted in the re-establishment of the CG, and establishment of Intersessional MASS Working Group (ISWG) in the coming October. Consequently, it was also agreed to postpone the third Joint Working Group (JWG 3), originally scheduled as September of 2023, to spring of 2024. Given the updated road map, changing the planned adoption of the mandatory code from MSC 110 (in 2025) to MSC 111 (in 2026) was agreed, while keeping the date of entry into force of the mandatory MASS Code as 1 January 2028.

3.6 Measures to Enhance the Safety of Ships Relating to the Use of Fuel Oil

Triggered by the global 0.50% sulphur limit, which has entered into force on 1 January 2020, further measures to enhance the safety of ships relating to the use of fuel oil have been discussed. MSC 106 adopted amendments to SOLAS Chapter II-2 to require that a bunker delivery note for the fuel delivered to the ship shall contain the flashpoint information.

At this session, the amendments to SOLAS Chapter II-2 to specify similar general provisions on fuel oil safety as set out in 18.3.1.1.3 of MARPOL Annex VI were approved. Also, joint MSC-MEPC *guidelines for taking fuel oil samples during bunkering* based on the existing guidelines (resolution MEPC.182(59)) was approved in order to establish a single sampling regime under both the SOLAS and MARPOL Conventions. The draft revised guidelines will be approved by subsequent MEPC and published as an MSC-MEPC Circular.

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