Transportation Safety Board of Canada
Bureau de la sécurité des transpo du Canada

Marine Occurrence Report

Crankcase Explosion

Oil Tanker "IRVING NORDIC" off Île aux Oeufs, Quebec 11 March 1993

Report Number M93M0002

Synopsis

On 11 March 1993, while en route from Matane, Quebec, to Grindstone, Quebec, with a cargo of refined petroleum products, the oil tanker "IRVING NORDIC" experienced a main engine crankcase explosion resulting in the total loss of propulsion power. The vessel was towed to Sept-Îles, Quebec, for inspection and repairs.

The Board determined that the crankcase explosion in the main engine of the "IRVING NORDIC" was caused most likely by the ignition of the crankcase oil vapour/mist as a result of hot spots in way of the No. 8 cylinder liner and/or combustion gas blow-by. The primary contributing factor to this occurrence was the substandard condition of the main engine.

Ce rapport est également disponible en français.

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1.0 Factual Information

1.1 Particulars of the Vessel

	"IRVING NORDIC"
Official Number	369846
Port of Registry	Saint John, N.B.[1]
Flag	Canadian
Type	Oil tanker
Gross Tons[2]	7,745
Length	132.26 m
Draught	F: 5.5 m A: 6.5 m
Built	1980, Saint John, N.B.
Propulsion	One 9M552 MaK diesel engine of 5,520 kW (7,500 BHP) driving a single controllable-pitch propeller
Owners	Irvingdale Associates Saint John, N.B.

1.1.1 Description of the Vessel

The "IRVING NORDIC" is a refined oil product carrier with accommodation and machinery located aft.

1 See Glossary for all abbreviations and acronyms.

2 Units of measurement in this report conform to International Maritime Organization (IMO) standards or, where there is no such standard, are expressed in the International System (SI) of units.

1.2 *History of the Voyage*

On 03 March 1993, when the "IRVING NORDIC" was off Yarmouth, Nova Scotia, a crankcase explosion occurred in the main engine. Knocking heard before the crankcase explosion and the condition of the No. 7 unit after that explosion suggest that the cause was associated with a fault in the piston top end assembly, bush or piston pin (see Appendix A). The No. 7 unit was replaced. The chief engineer became concerned about the excessive liner wear found in the No. 7 unit and decided to inspect the other eight liners at the first opportunity. The vessel then continued her voyage to Matane.

While at Matane and discharging cargo on 10 March 1993, the engineers removed the exhaust valves from cylinders Nos. 1, 2 and 4 and checked, by touch, the liner wear in these units. Some wear was detected on the No. 2 liner but, because of the limited time in port, it was decided to postpone further investigation until the next port.

The same afternoon, the "IRVING NORDIC" departed Matane for Grindstone, but, because of ice conditions, stopped for the night.

At about 1000[3] the following morning, the vessel resumed her voyage. The second engineer was on watch in the engine-room performing routine maintenance. At about 1112, he heard a thump from the main engine and observed white smoke and oil vapour coming from the explosion-relief doors on the starboard side of the main engine. Realizing that a crankcase explosion had occurred, he manually shut down the engine and evacuated the engine-room. There was no fire and none of the 20 crew members were injured. After assessing the situation, the engineers returned to the engine-room. An initial investigation revealed that the No. 8 liner, piston, wrist pin and connecting rod had sustained damage and would have to be replaced. As the spares had been utilized for repairs to the No. 7 unit, no permanent repairs could be carried out and the vessel was towed to Sept-Îles. Meanwhile, preparations had commenced for further inspection and repairs.

At the time of the crankcase explosion, the vessel was carrying 1,005 tonnes of refined petroleum products, 6,600 tonnes of water ballast, 587 tonnes of intermediate fuel oil (IFO), 85 tonnes of diesel fuel, and 20,000 litres of lubricating oil.

1.3 *Main Engine Damage*

At Sept-Îles, all main engine units were dismantled and inspected in the presence of representatives from MaK (engine manufacturer), Lloyds Classification, Canadian Steamship Inspection and insurance underwriters.

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3 All times are EST (Coordinated Universal Time (UTC) minus five hours) unless otherwise stated.

Amongst the damage found to the main engine and observations made, those directly related to the investigation were the following:

1) Abnormal wear beyond the manufacturer's recommended limit to liners in units nos. 2, 3, 8 and 9 and over 50 per cent wear in the No. 6 unit.
2) Abnormal ring groove clearances to pistons in all units except unit No. 7.
3) The top piston ring in units Nos. 2, 8 and 9 and the No. 4 piston ring in units Nos. 2 and 9 were broken.
4) The top piston ring in unit No. 4 had been previously installed upside down; the last overhaul by the ship's staff was on 06 July 1992.
5) All main and bottom-end bearings were scored and some showed impressions of metal strands from the final lubricating oil safety strainer.
6) The final lubricating oil safety strainer was destroyed.
7) The No. 8 unit connecting rod and piston pin were seized.
8) A hard white/grey deposit was on the piston crowns.
9) Four crankcase doors were slightly damaged and no longer provided an effective crankcase seal.

1.4 *Certification*

1.4.1 *Vessel*

The vessel was certificated, equipped and manned in accordance with existing regulations.

1.4.2 *Personnel*

Both the chief engineer and the second engineer held valid certification appropriate for the position and the trade in which the vessel was engaged.

1.5 *Personnel History*

The chief engineer had been assigned to the "IRVING NORDIC" for about a year on a rotation system and his last tour of duty commenced on 07 January 1993. Before joining his present employer, he had extensive experience as a chief engineer, including three years' experience with the same type of engine.

The second engineer, who was the engineer on watch, joined the "IRVING NORDIC" on 19 January 1993 for a three-month period. With his present employer, he had served in various capacities as an engineer officer on motor-driven vessels equipped with other engine types.

1.6 Fuel Oil Analysis

Fuel oil samples were taken from the ship's settling tank and day service tank and sent to an independent laboratory for analysis. The analysis indicated that the fuel was within the specifications recommended by the engine manufacturer.

1.6.1 Lubricating Oil Analysis

Routine lubricating oil samples were taken by the vessel's engineers at 500-hour intervals and sent to a laboratory specializing in oil analysis.

The last lubricating oil sample was taken on 12 December 1992, with 900 running hours on the oil. The results revealed an abnormal level of chromium in the oil.

After the explosion, a main engine lubricating oil sample was taken and analyzed by an independent laboratory. The results showed that the sample contained less than 0.2 per cent water (within acceptable limits), a trace of fuel oil and elevated levels of copper, chromium, iron and aluminium.

1.6.2 Piston Crown Deposit Analysis

A sample of the white/grey deposit on the piston crown was taken and sent to an independent laboratory for analysis. The results showed 72 per cent calcium sulphate, 21.33 per cent calcium, 0.23 per cent sodium and 0.14 per cent potassium; the remainder was various trace elements and ash.

1.7 Engine Maintenance Inspection

The recommended main engine routine maintenance inspection was carried out according to the manufacturer's operations manual and records were maintained. One copy was retained on board and one sent to the company.

The manufacturer recommends that liner-wear measurements be taken at 10,000-hour intervals. The recommendation was generally followed.

The main engine pistons were modified at a subsequent dry-docking of the vessel in September 1993 in accordance with the recommendation of a manufacturer's representative who was in attendance. Indications from an early inspection after the dry-docking were that the subsequent performance of the main engine had been satisfactory.

1.7.1 *Cylinder Liner Wear*

Liner wear is unavoidable in any engine. Excessive liner wear would result in combustion gas blow-by in the crankcase. Wear rates are kept to a minimum by ensuring that an oil film is evenly maintained between the rings and the liner. Under normal operating conditions, maximum liner wear occurs at or near the combustion area.

The two types of cylinder liner wear are corrosive liner wear and abrasive liner wear.

1.7.1.1 *Corrosive Liner Wear*

When fuel is burned in a cylinder, water, carbon dioxide and sulphur oxides are produced. If condensation occurs, carbon dioxide and sulphur oxides will go into solution, forming strong acids. Research has shown that the corrosion wear occurs primarily during manoeuvring, low-powered operation and after shut-down. An increase in the rate of cylinder lubrication during manoeuvring, low-power operation, and turning the engine a few revolutions after shut-down effectively reduce the liner corrosion. There was no visual evidence to suggest corrosive liner wear in this case.

1.7.1.2 *Abrasive Liner Wear*

Abrasive liner wear occurs when the piston moves within the liner. The wear is caused by metal-to-metal contact between the liner and the rings because of poor liner lubrication or abrasive particles caught between the rings and the liner, destroying the oil film.

The nominal diameter for a new liner fitted to a MaK 552 engine, as given in the MaK Operating Instruction Manual, is 450 mm. The wear limit is 451 mm and an out of roundness of 0.4 mm.

Following the occurrence, the No. 8 liner showed heavy scoring in the forward part of the liner with elongated areas of what appeared to be skirt material (aluminium-based) on its surface. The liner, as measured, showed 451.85 mm in the fore-and-aft direction and 451.32 mm in the port and starboard direction, with a 0.53 mm out of roundness. According to the records, there were 14,738 running hours on the liner since new. (For information on the salient condition of all liners and piston rings, see Appendix B.)

According to the manufacturer, the cylinder liner wear rate is expected to be between 0.010 and 0.015 mm/1,000 hours' running time. The cylinder liner wear measurements taken at the time of the occurrence and during routine maintenance periods showed that the average wear rates varied between 0.157 mm/1,000 hours and 0.223 mm/1,000 hours; i.e., over 14 times the normal wear rate.

Between the last two consecutive routine maintenance inspections on 07 May 1992 and 15 March 1993, the number of running hours on the No. 8 liner was 4,307, giving a wear rate of 0.3761 mm/1,000 hours, i.e., 25 times the normal wear rate.

Perusal of the liner measurements taken during the period between June 1990 and March 1993 revealed that higher-than-normal wear rates were experienced in all but the No. 5 liner. In the latter, the wear rates were marginally above normal. Further, six out of the nine units that had been overhauled by the ship's crew since 1991 showed abnormal liner wear rates.

The lubricating oil system and the cylinder lubricators were checked following the occurrence and found to be functioning satisfactorily.

1.7.2 *Piston and Piston Rings*

A number of the ring groove widths on each piston with the exception of piston No. 7 had exceeded the manufacturer's limit, necessitating the replacement of the piston.

Excessive ring groove width allows the piston ring to hammer the ring groove landing, resulting in higher wear of the ring and the groove.

As the piston moves down in the liner, oil from the liner wall is forced into the space below and behind the ring. As the piston moves up, the oil is transferred to the space above the ring. The compression ring is lubricated in this manner. Excessive groove clearance would result in higher than normal lubricating oil consumption, and the combustion-generated heat would result in carbon formation in the groove. This, in turn, interferes with the lubrication process and increases the liner wear rate. Liner wear material becomes trapped in this carbon formation and further aggravates the problem. Ring breakage may result.

In this instance, six piston rings were found broken; two of which were located in the No. 8 unit. In the latter, the No. 1 piston ring was broken into seven pieces and the No. 5 (oil scraper) ring, into two. The No. 8 piston showed heavy scuffing on the crown. There were bright streaks on the piston skirt and scuffing marks below the oil scraper ring. The ring grooves had some dirt in them. There was some hard white/grey deposit on the piston crown. The records indicated that the consumption of lubricating oil was higher than expected during the year before the occurrence.

1.7.3 *Bearings*

The main and bottom-end bearing shells, with the exception of the No. 7 cylinder bottom-end bearing shells, all showed signs of scoring and some showed the impression of filter material from the final lubricating oil safety strainer. The scoring on the bearing shell surfaces was in excess of the manufacturer's criteria for reuse.

1.7.4 *Connecting Rod and Piston Pin*

Lubrication oil to the bearing bush is supplied under pressure from the engine lubrication system. Should the supply of lubricating oil to the bearing bush be interrupted or fail during operation, seizure of the pin in the bush would occur. In this instance, the No. 8 piston pin was found seized in the connecting rod bearing bush, and failure of the lubricating system would be the most probable but not the only possible cause.

1.7.5 *Crankcase Explosion*

In diesel engines, crankcase explosions occur when, in the presence of hydrocarbon vapour/mist, there is a source of ignition/hot spot.

1.8 *Company Employment and Training Practices*

The crew members on board the "IRVING NORDIC" were employed on a rotational basis. There are no specific criteria established by the company to assign engineers to a vessel. The company believes that, as the engineers employed are in possession of valid maritime certificates of competency, they are knowledgeable and competent enough to perform their duties, if necessary, by referring to the machinery manuals. There is no company-established training program in place.

2.0 *Analysis*

2.1 *Cause of the Crankcase Explosion*

The scoring and the material deposited on the No. 8 liner, and the scuffing of the piston crown depict conditions that would be consistent with a breakdown of the cylinder liner lubrication film. This breakdown would have resulted in metal-to-metal contact between the piston rings and the liner with consequential hot spots on the liner. Further, the combustion gas blow-by can also ignite hydrocarbon vapours. Thus, these hot spots and/or combustion gas blow-by would likely cause ignition of the lubricating oil vapour/mist, resulting in the crankcase explosion.

Prompt action by the second engineer in shutting down the main engine likely averted a more serious secondary explosion.

2.2 *Final Lubricating Oil Safety Strainer Failure*

The final lubricating oil safety strainer is thought to have failed after the 03 March occurrence as no evidence of filter material was noted when the No. 7 bottom-end bearing was opened up at that time. The precise time of the disintegration of the safety oil strainer is not known. However, this information is not considered significant because it did not influence the outcome of this occurrence.

2.2.1 *Lubricating Oil and Main Engine Wear*

As the main engine components are made of different metals, the presence of high levels of certain metals in a lubricating oil sample can be associated with engine component wear. For example, the presence of copper in the oil could indicate bearing wear; chromium, piston ring wear; iron, liner and piston ring wear; and aluminium may be introduced through piston wear. The elevated levels of these four elements in the lubricating oil sample are consistent with the wear found in the engine.

As the No. 8 piston pin had been seized in the connecting rod bearing bush, it would indicate that the supply of lubricating oil to the bearing bush had been interrupted during operation.

2.3 *Piston Crown Deposits*

When the piston crown deposits came in contact with the cylinder lubrication, an abrasive compound was formed, which would have contributed to the cylinder liner wear.

2.4 *Monitoring of Wear Rate and Preventive Action*

Periodic cylinder liner inspections were carried out and the liner wears were recorded. From this, the liner wear rate per 1,000 hours could have been derived. This information, when used in conjunction with other available information, e.g., the higher than normal consumption of lubricating oil, would have provided an overview of the overall condition of the engine. In this instance, an oil sample analysis in December 1992 indicated an abnormal level of chromium (piston ring material) and, as abnormal liner wear rates were observed in some units during their past liner inspections, further investigation to determine the cause of the problem would have been in order. During the course of the investigation, no evidence or record was presented to suggest that such action had been initiated until after the 03 March explosion.

2.5 *Employment and Monitoring Practices - Training and Safety*

A close monitoring of the main engine maintenance program by the company would have been in order since main engine maintenance is essential for the efficient, economic and safe operation of the vessel, there was a frequent turnaround of personnel, and there was no specific company training program in place. However, as abnormal wear rates of the main engine components had continued for a period of time without effective action, it is apparent that the company did not effectively monitor the condition of the main engine.

3.0 *Conclusions*

3.1 *Findings*

1. The substantial wear on the cylinder liners can be attributed to the breakdown/destruction of the lubricating oil film because of the abrasive action of the deposits of combustion, metallic debris from the broken piston rings and worn liner material.

2. The piston ring failures were most probably a result of excessive ring groove clearance.

3. The top piston ring in unit No. 4 had been installed upside down.

4. The lubricating oil sample taken before the occurrence revealed abnormal levels of chromium but no evidence or record was found to suggest that follow-up action had been initiated.

5. Abnormal cylinder liner wear rates were found in six out of the nine units that had been overhauled since 1991.

6. The bearing shell surfaces were scored by metal from the final lubricating oil safety strainer which disintegrated in the crankcase explosion.

7. The breakdown of the liner lubricating oil film in the No. 8 unit resulted in hot spots on the liner.

8. The hot spots in the No. 8 unit and/or the combustion gas blow-by resulted in the ignition of the main engine crankcase oil vapour/mist.

9. Prompt action by the second engineer in shutting down the main engine likely prevented a more serious secondary explosion.

3.2 *Causes*

The crankcase explosion in the main engine of the "IRVING NORDIC" was caused most likely by the ignition of the crankcase oil vapour/mist as a result of hot spots in way of the No. 8 cylinder liner and/or combustion gas blow-by. The primary contributing factor to this occurrence was the substandard condition of the main engine.

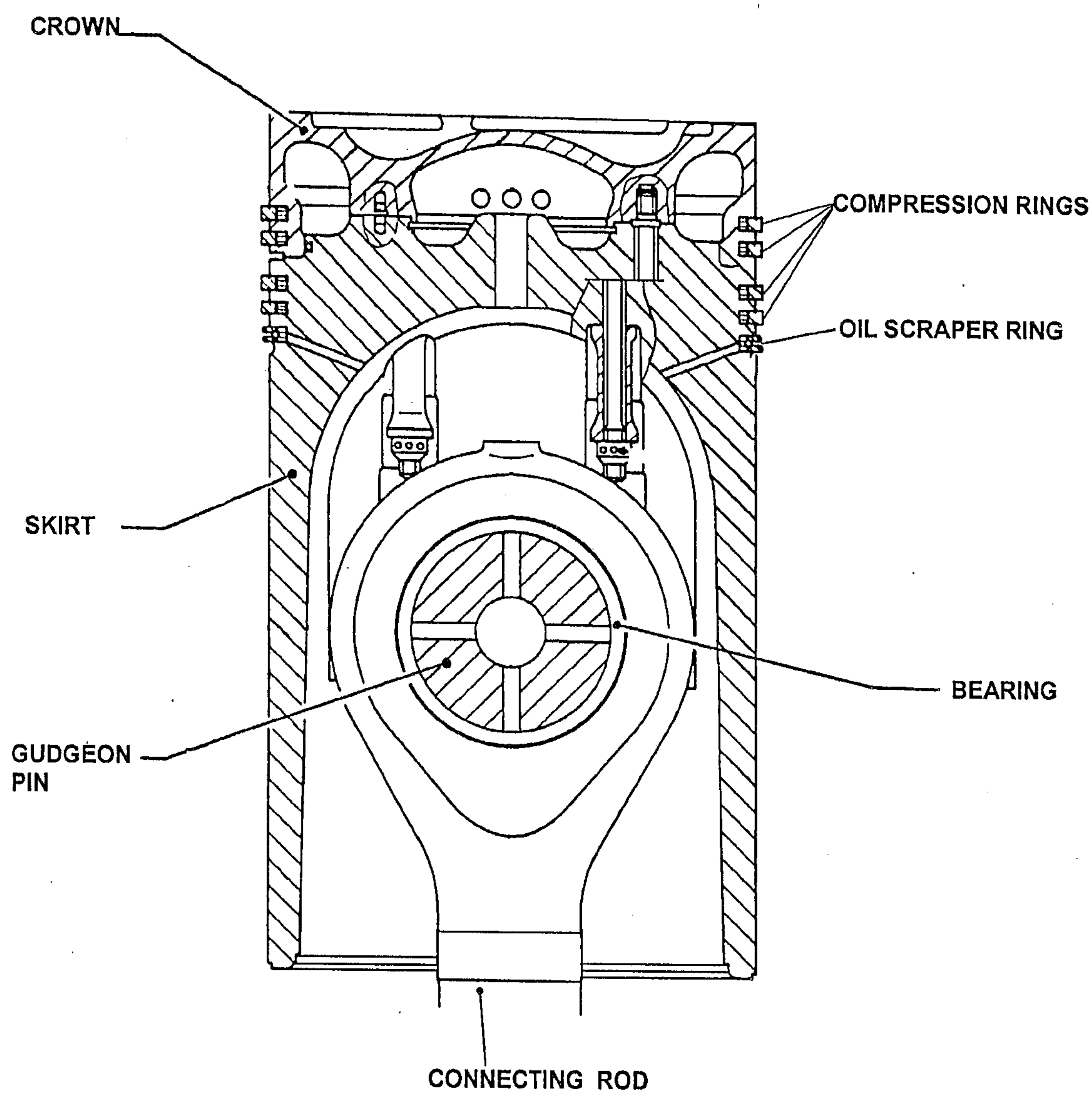
4.0 Safety Action

4.1 Action Taken

Following the accident, the main engine was completely overhauled. In September 1993, the vessel was dry-docked and the main engine was again examined for excessive wear. Subsequently, the main engine piston crowns were modified in accordance with the manufacturer's recommendations. During the main engine overhaul, the company changed the grade of the fuel oil to maintain a clear running engine.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board, consisting of Chairperson, John W. Stants, and members Zita Brunet and Hugh MacNeil, authorized the release of this report on 16 August 1995.

Appendix A - Sketch Showing Typical Medium-Speed Piston



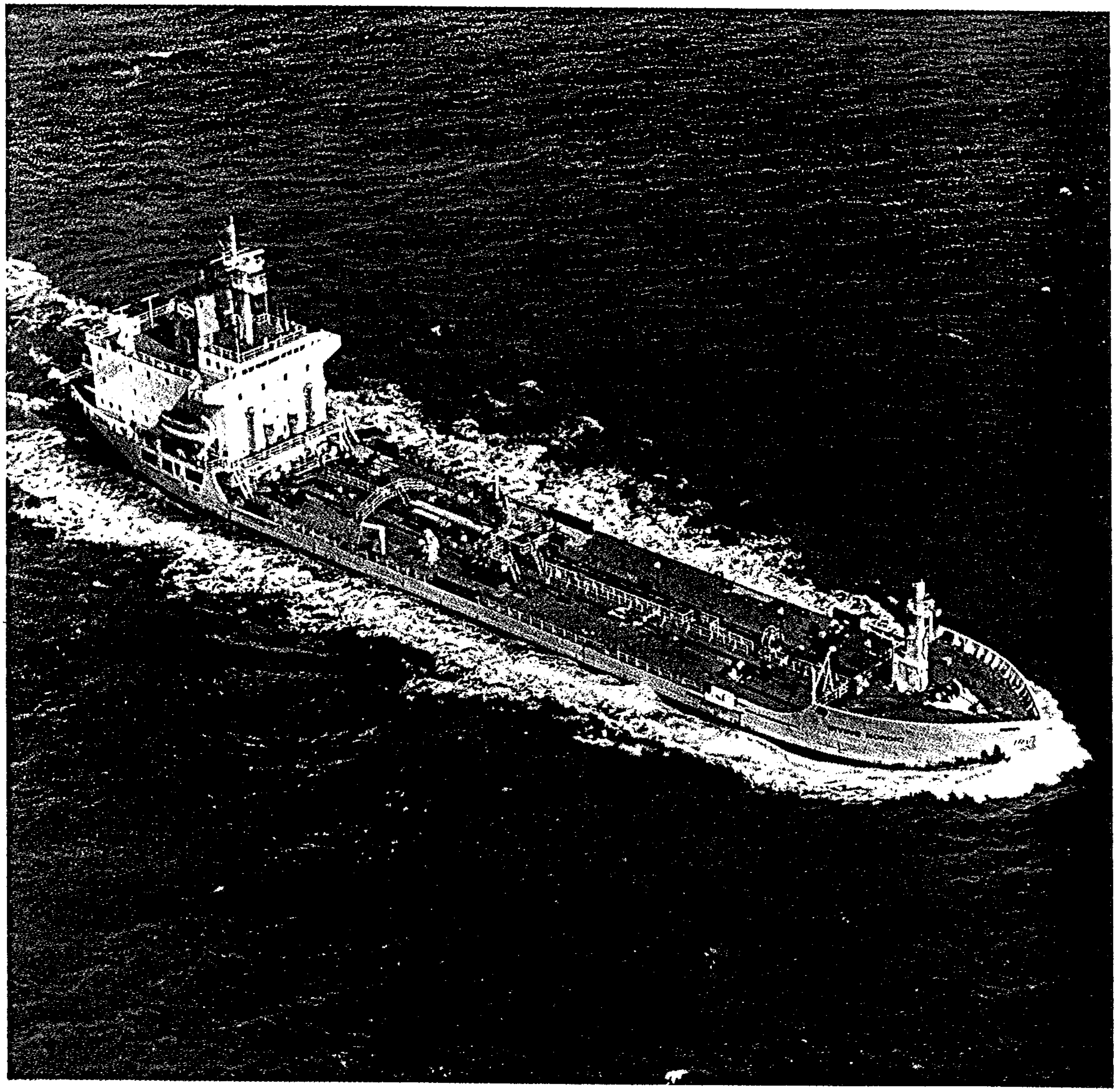
Appendix B - Table Depicting the Conditions of Liner and Piston Rings

This table was compiled by the TSB and is based on the observations made and the information obtained during the investigation. The table depicts the condition of liners and piston rings and is solely intended to present an overview of the general condition of the main engine.

Unit No.	Liner Wear Reading		Ovalness Readings		Piston Ring	
	Max (mm)	Limit (mm)	Max (mm)	Limit (mm)	Groove Condition	Broken
1	450.07	451.00	0.03	0.30	1 & 5 over limit	None
2	451.95	451.00	0.60	0.30	1, 4 & 5 over limit Rings badly worn	1 - 8 pcs 4 - 2 pcs
3	451.70	451.00		0.30	1 ring groove over 1 mm wear	None
4	450.43	451.00	0.02	0.30	1 ring installed upside down - all rings had a build-up of carbon	None
5	450.21	451.00	0.12	0.30	1 & 5 over limit	None
6	450.43	451.00	0.02	0.30	1, 3 & 5 over limit	None
7	*	*	New	Unit	*	*
8	451.85	451.00	0.53	0.30	Piston seized	1 - 7 pcs 5 - oil scraper ring - 2 pcs
9	451.30	451.00	0.06	0.30	1 - face contour flattened 3 - ring free in groove, contour evident 5 - free movement	1 - 2 pcs 4 - 5 pcs

Appendix C - Photograph

IRVING NORDIC



The M.V. "IRVING NORDIC" is an ice-strengthened product carrier designed to carry refined oil cargoes.

Le N.M. «IRVING NORDIC» est un navire-citerne renforcé pour la navigation dans les glaces et conçu pour transporter des produits pétroliers raffinés.

Appendix D - Glossary

A	aft
BHP	brake horsepower
EST	eastern standard time
F	forward
IFO	intermediate fuel oil
IMO	International Maritime Organization
kW	kilowatt(s)
m	metre(s)
mm	millimetre(s)
N.B.	New Brunswick
pcs	pieces
SI	International System (of units)
TSB	Transportation Safety Board of Canada
UTC	Coordinated Universal Time