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Mesothelioma Risk Among Maritime Workers According to Job Title: Data From the Italian Mesothelioma Register (ReNaM)

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Abstract

Background: *The study describes the 466 cases of malignant mesotheliomas (MM) collected by the National Mesothelioma Register (ReNaM) in Italy from 1993-2018 relating to subjects with exclusive asbestos exposure in merchant or military navy.* **Methods:** *The cases among maritime workers represent 1.8% of the total patients with defined exposure registered in the ReNaM, of which (45.4%) were among merchant maritime workers and 254 cases (54.5%) among the navy. The distribution by site of mesothelioma showed 453 (97.2%) MM cases of the pleura, 11 (2.3%) of the peritoneum, and 2 (0.4%) of the tunica vaginalis of the testis. With regard to occupational exposure, it was classified as certain in 318 (68.2%) cases, probable in 69 (14.8%) cases, and possible in 79 (16.9%) cases.* **Results:** *Among the 23 classified jobs, the highest percentages of certain exposures are among naval engineers, motor mechanics, machine captains, and sailors. Machine crew accounted for 49.3% of the cases, and deck crew for 27.6%. All cases began exposure on board between 1926 and 1988. Seamen were exposed to asbestos while at sea by living onboard ships and from the continual release of asbestos fibers due to the motion of a vessel.* **Conclusions:** *Epidemiological surveillance through the ReNaM has allowed us to verify among cases in the maritime, navy, and merchant marine sectors that, in the past, subjects were exposed regardless of the ship's department where they have provided service; therefore, all these cases must be considered occupational diseases.*

1. Introduction

Malignant Mesothelioma (MM) is a rare and lethal cancer of the pleura, peritoneum, pericardium, and tunica vaginalis testis caused by asbestos, the main etiologic agent of this cancer. This cancer has a long latency, and there is no known safe level of asbestos exposure [1].

Asbestos was widely used in industry in the last century, including shipbuilding. The use of asbestos in both merchant and military vessels in the past has been extensive and well-documented. It has been used in the compact and friable forms, mainly for thermal insulation of structures and pipelines for fluids, fire protection, sound absorption, anti-condensation, soundproofing, insulation, and other products used on board ships [2-6].

From the early 1930s to the mid to late 1970s, naval and commercial shipyards used hundreds of tons of asbestos, primarily chrysotile and amphiboles asbestos-containing insulation, to build and repair maritime vessels. For example, warships contained roughly 30 and 500 tons of asbestos insulation on bulkheads, pipes, and machinery [2, 7, 8].

Hollins (2009) and Franke (2011), in their reviews, reported that since the 1880s up to the 70s and beyond, at least until 1978-1980, amosite and chrysotile asbestos fiber type, and lesser extent crocidolite, were used extensively as insulating materials on naval ships. In the 1930s, the U.S. (United States)

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Navy also approved using amosite that was required in many military specifications for insulation and other materials on ships. Asbestos-containing products on ships included joiner bulkhead systems in living spaces, insulation on both hot water and steam piping, inside and outside of boilers and cold-water pipes to avoid condensation, tanks, and also in machinery casings, block insulation, asbestos cement, and lagging, pre-formed asbestos insulation, flanges and valves, and vinyl asbestos tile for decking and flooring.

Asbestos was sprayed onto deck heads, bulkheads, and the inside face of the hull, pipes, and machinery were insulated with molded sections containing asbestos. Asbestos was applied in rooms and on installations inside and outside the engine rooms, so potentially the entire crew could have been at risk [3-4].

Although chrysotile was most commonly applied aboard, suspended brown asbestos was detected inside and outside the engine room on a frigate, brown asbestos was also found aboard Norwegian civilian vessels inspected during the 1970s [2].

It has been hypothesized that vibrations during sailing would release asbestos fibers to the breathing atmosphere in most areas aboard or from insulation repairs conducted during travel at sea, including ruptures, failures, or blowouts on the steam piping. In submarines, active handling of asbestos was predominantly limited to the engine rooms, but the closed environment during submerged might have put all crew at risk. Onboard operations such as inspections, maintenance, repair, and refitting would involve contact with asbestos for crew members. Seamen were exposed to asbestos in-place, as environmental asbestos exposure, continually due to their living onboard ships and the continual release of asbestos fibers due to the vessel motion. Moreover, structural corrosion caused by salt water and air could facilitate the clearance of asbestos from its supporting matrix [5, 9, 10].

Franke (2011) studied U.S. Government and Navy knowledge regarding the health hazards of asbestos between 1900 to 1970. He stated that the Navy continued to require asbestos-containing materials on ships but recommended that proper precautions be taken when handling asbestos. Nevertheless, until 1970, neither the military nor the private sector believed that the myriad of asbestos-containing products considered "encapsulated" (e.g., gaskets, brakes, bakelite) would have posed a health hazard to those working with them. The Navy attempted to control exposures to concentrations that it considered acceptable. It began looking for substitute materials during the 1970s, and most uses ceased by about 1985 [4].

Among the first scientific publications indicating probable asbestos exposure-related effects in a population of seamen it must be mentioned those by Jones (1984) Velonakis (1989), and Selikoff (1990) [11-13] that reported radiological anomalies in merchant marine seamen and American marine engineers. The prevalence of asbestosis changes differed in seamen who served in different ship departments, deck, engine room hands, bargemen, light tenders and boatmen, engineering and radio officers, pilots ships and foremen, lighters, and other vessel crew. Darby (1990) [14] reported an excess of deaths in the British Royal Navy. The association between occupational seafaring and excess risk of mesothelioma has been reported in numerous studies, many sand studies on seafarers conducted in the Nordic countries. Nordic seafarers on merchant vessels had an overall increased risk of pleural cancer, and an excess of mesotheliomas was described among Finnish machinists, engine room crews, and deck crew, but also among seamen in Denmark, Norway, Sweden, and Iceland [15-29]. The same findings were described among merchant marine seamen and U.S. Navy [30]. More recently, a series of studies conducted on seamen from the Nordic countries [31] studied incidence, mortality, and survival in malignant pleural mesothelioma before and after the asbestos ban in Denmark, Finland, Norway, and Sweden and found that in these countries, the male incidence trends for MM climaxed and started to decrease, indicating that the prevention of exposure was beneficial. The same results were reported by Forsell (2022) [32] on cancer incidence between 1985 and 2011 in a Swedish seafarer's cohort. A significant decreasing trend for cancer risk was found. Increased risks of cancer in seafarers reported in the literature stem primarily from older periods of seafaring up to 1999 at the latest [16, 20, 23, 25]. Petersen (2020), in a study

among seafarers employed on Danish ships during 1986-1999, reported that among seafarers with first employment before 1992, the overall mortality was high; this excess in mortality was evident primarily among non-officers on board tankers and smaller ships [24].

Excess mortality from mesothelioma was recently reported by Boice (2020) and Till (2022) [33-34] among atomic veterans; it was explained by asbestos exposure among enlisted naval personnel. The sources of exposure were determined to be on navy ships in areas (or with materials) with known asbestos content.

Regarding Italy since 1992, Rapiti [35], in a cohort of more than 2000 seamen, found an increased risk of respiratory cancer among subjects with an occupational history of sailing, possibly due to past asbestos exposure. In a study of mesothelioma in the Trieste Province, between 1968 and 1987, 19 cases (11.2%) were reported for various trades of seamen in the Navy and merchant marine including machinist (9), Navy official (4), cook (2), electrician (2), cabin-boy (1) and steward (1) [36].

Bianchi (2005) [37] reviewed pleural mesotheliomas diagnosed in the Trieste-Monfalcone area among seamen in 1973-2003; they had served in the Italian Navy, in the Merchant Navy, or both and showed long latency periods. The author stated that mesothelioma in seamen should be considered an occupational disease. Mensi (2006) [38] reported eleven cases of mesothelioma among Italian navy personnel (stokers, bomb squad, electrical maintenance man, gunners, and simple sailors). Larese Filon (2013) [39] reported that mesothelioma in seamen and marine engineers represented about 2.5% of the overall Italian mesothelioma cases with a very long latency period (47.6 +/- 9.6 years).

The International Convention for the Safety of Life at Sea (SOLAS) has banned the use of asbestos or materials containing asbestos on merchant ships worldwide only since 1 January 2011. Therefore, due to the recognized long latency time of the onset of mesothelioma, asbestos remains a serious public health concern in the maritime sector. Moreover, possible asbestos exposure could still occur where, more or less accidentally, on asbestos-free ships, spare parts containing asbestos were installed during maintenance. These components are still produced and sold in several countries around the world. Considering the high number of workers employed, studying and monitoring exposure to asbestos in the maritime sector is crucial. The most recent available Italian data report that in the maritime transport sector, on average yearly, 42,348 units are employed (ISTAT 2020 last accessed 3 April 2023 http://dati.istat.it/index.aspx?queryid=20596). Meanwhile, in the Navy sector, there are 29,567 units engaged by the Navy as of 31/12/2021 (https://www.difesa.it/Amministrazionetrasparente/persomil/Documents/PERSONALE/Conto_annuale_2021/02_Conto_MM.pdf last accessed 3 April 2023).

Therefore, this study aims to describe the cases on MM collected by ReNaM in 1993-2018 relating to subjects with exclusive asbestos exposure in merchant or military Navy, military or merchant seamen workers.

2. Methods

Data were collected by ReNaM, a national epidemiological surveillance system characterized by a network of regional operating centers ('Centri Operativi Regionali': COR) established in all Italian regions using a systematic active search of MM over the entire national territory with standard criteria for active case search, diagnosis classification, and qualitative assessment of asbestos exposure obtained occupational and residential histories of exposure and lifestyle habits by interviewing affected subjects (or next of kin) through a standardized questionnaire. Asbestos exposure was categorized as occupational" (with three degrees of certainty: "definite", "probable", "possible") or "non-occupational" (in-house, environmental, and other non-occupational–such as leisure-time-related activities). "Unlikely"exposure was assigned to subjects whose information was inadequate or asbestos exposure could be reasonably ruled out [40].

Subjects with occupational exposure exclusively in the maritime sector (codes 75.22 and 61 of the Italian classification of economic activities' ATECO 1991') [41] were analyzed. In this study, we did not consider the workers of the fisheries (ATECO code 05) nor those of the military arsenals or shipyards (ATECO code 35).

The occupational codes of the Italian classification of economic activities 'ATECO 1991' and the Classification of ISTAT Professions 1991 [42] were based upon the salaried reporting system of the industry to which each examinee belonged. For each case, it was used the ISTAT codes of professions of the national ReNaM database integrated with the notes on the jobs and on the ships where the subject has been embarked if present in the same database.

We converted the ISTAT codes ('ATECO 91') into the maritime sector's, reported tasks and professional qualifications of seafarers, both as the Code of Navigation, concerning the regulation of professional titles and as Collective Agreement National Work for the Private Sector of The Shipping Industry [43, 44] to examine homogeneous groups of people exposed. "Maritime work" means any work activity on board a ship at sea or in port. Anyone who performs "maritime work" usually belongs to a specific category of workers called "people of the sea". Maritime work as a civilian activity occurs in three sectors: transport, fishing, and yachting. As far as transport is concerned, this refers to the work performed on board ships used for the transport of goods and passengers, "beyond straits" on the oceanic routes of international traffic, on "short" routes of national and Mediterranean cabotage, and onboard special vessels operating "offshore", for laying pipelines, the construction and installation of platforms, etc., as well as onboard service vessels in ports, such as tugs, pilot units, vessels involved in bunkering, i.e., at refueling, etc. As far as pleasure boating is concerned, it is working on board boats designed for sporting or recreational purposes from which the pursuit of profit does not exist, but which the law allows that they can also be employed in economic activities, for commercial purposes, through contracts of lease and rental ("nautical charter") or for teaching pleasure boating, as well as a support unit for scuba diving for sporting or recreational purposes. The maritime personnel recognized by the harbor master's offices are deck personnel, engine personnel, multi-skilled personnel, health personnel, room personnel, kitchen, and household personnel, and personnel assigned to various services. Each category includes a large number of jobs and qualifications. For the navy, regardless of military rank (admiral, ship captain, ship lieutenant, midshipman, marshal, sergeant, graduates, enlisted men and soldiers without rank or cadets) and of the navy corps to which they belong) general staff, navy engineers (naval weapons, naval engineering, infrastructures), medical units, maritime military commissariat, port authorities, maritime military crews) from the point of view of the occupational risk of asbestos exposure, the various jobs can be considered to overlap with those of the merchant marine (Table 1 supplementary material).

Some maritime, military, and merchant workers performed more than one task because, during their professional careers, they had promotions or changed jobs and qualifications, which resulted in 1451 circumstances of asbestos exposure. Among these, we have excluded those who, for example, had a period of exposure due to military service in the Navy. Only 466 subjects with exclusive navy or merchant marine exposure were considered and analyzed jointly. The 49 jobs among navy workers and 51 among merchant marine workers were classified as shown in Table 2 supplementary material.

Qualitative assessment of retrospective exposure is key in identifying subjects exposed to asbestos and examining the association between asbestos exposure and mesothelioma occurrence [45]. Quantitative data on asbestos exposure, i.e., information about measurement (fibers/cm^3) at the workplace for any subjects, are not available in the ReNaM database. The exposure level for the analyses was attributed to certain, probable, and possible following the qualitative classification of exposure as reported in the ReNaM guidelines based on responses and information collected from the patient through a standardized questionnaire evaluated by industrial hygienists [40] and in agreement with the literature [2-5, 10].

- Certain occupational exposure was attributed to subjects who used asbestos or materials containing asbestos.
- Probable occupational exposure was attributed to subjects who had worked in a firm where asbestos was used but whose exposure could not be documented together with the frequency of direct or bystander asbestos exposure.

- Possible occupational exposure was attributed to subjects who had worked in an economic sector where asbestos had been used together with the frequency of direct or bystander asbestos exposure, such as typical tasks, work practices, and materials used over time.

The data analyzed refer to the incidence period 1993-2018. Descriptive analysis has been performed: mean and the median age at diagnosis, mean and the median age at the beginning of exposure, mean and median duration of exposure, and mean and median latency by morphology were calculated with their Standard Deviation using STATA 12 software (College Station, TX: StataCorp L.P.). The first asbestos exposure was considered to have coincided with the start of employment in the job during which the initial asbestos exposure had occurred. Similarly, the duration of asbestos exposure was approximated by duration of employment in the job with probable or definite asbestos exposure. The latency period was defined as the period between the first exposure to asbestos and the certified diagnosis of MM calculated for each maritime worker job. The distribution of cases by job, qualitative exposure to asbestos, period of exposure beginning (1926-1960; 1961-1988), and period of incidence (1993-2000, 2001-2010, 2011-2018) are shown too.

3. Results

The 466 cases among maritime workers, as first defined, represent 1.8% of the total cases with defined exposure registered between 1993 and 2018 in Italy [46], of which 212 (45.4%) cases among merchant maritime workers and 254 (54.5%) cases among navy. Among the cases with exclusive exposure in the military defense category ReNaM code economic categories 35, the 254 subjects exposed in the navy represent 66.6%of the cases [46]. Among the cases with exposure in the ReNaM code economic categories 30 maritime transport category, the 212 exposed subjects with exclusive exposure represent 47.4% of the cases [46].

The 466 cases were all male subjects except one female of the navy in charge of surveillance. The distribution by site of mesothelioma showed 453 (97.2%) MM cases of the pleura, 11 (2.3%) of the peritoneum, and 2 (0.4%) of the tunica vaginalis of the testis. In terms of diagnostic certainty, there were 383 (82.1%) certain, 43 (9.2%) probable, and 40 (8.5%) possible mesotheliomas. Regarding histotype, it was epithelioid for 285 (61.1%) cases, sarcomatous in 37 (7.9%) cases, biphasic in 45 (9.6%) cases, malignant in 51 (10.9%) cases and undefined in 48 (10.3%). With regard to occupational exposure, it was classified as certain in 318 (68.2%) cases, probable in 69 (14.8%) cases, and possible in 79 (16.9%) cases [40]. Mean age at diagnosis was 71.9 years SD 9.5 median 76 range (36-96), mean age at the beginning of exposure was 20.7 years SD 4.8 median 20 range (14-55), mean duration of exposure was 20.8 years SD 15.2 median 20 range (1-58), mean latency was 55.6 years SD 10.5 median 52 range (17-82).

The 11 cases of peritoneal MM were all male with a mean age at diagnosis of 63.45 years SD 15.18, the beginning of exposure in the years between 1936 and 1984 and age at the beginning of exposure between 17 and 23 years, average duration of exposure 16.81 years SD 12.69, mean latency 44.09 years SD 15.51. Five had been exposed in the merchant marine and 6 in the navy. The jobs were a helmsman on merchant ships, a submarine commander, and nine naval engineers, including 5 in the navy and 4 in the merchant marine.

The two cases of TVT MM with age at the beginning of exposure, both of 20 years, started respectively in 1976 and 1941, duration of exposure of 2 and 4 years, age at diagnosis of 46 and 82 years, and latency of 26 and 62 years. Both subjects were exposed in the Navy as a ship electrician and a tugboat pilot.

Concerning the task, 49.3% of the cases belonged to the machine crew and 27.6% to the deck crew (Table 1).

Among the 23 classified jobs, the highest percentages of certain exposures in descending order are among naval engineers, motor mechanics, machine captains, and sailors, the most represented jobs among the 466 cases (totaling 285 cases equal to 61.1% of all cases). In 21 jobs, except for the two classified as various services boards and various services on services, over 50% of the patients had certain exposure (Table 2).

Table 1. Distribution of cases (number and percentage) by task and qualitative exposure assigned.

	Exposure			
TASK number	**Certain (%)**	**Probable (%)**	**Possible (%)**	**Total (%)**
1. Meck Crew	67 (51.9)	27 (20.9)	35 (27.1)	129 (100)
2. Medical Staff on Board	-	-	-	-
3. Various Service Crew	47 (62.6)	15 (20.0)	13 (17.3)	75 (100)
4. Room Family Kitchen Crew	14 (53.8)	8 (30.7)	4 (15.3)	26 (100)
5. Local Traffic Crew	3 (50.0)	1 (16.6)	2(33.3)	6 (100)
6. Machine Crew	187 (81.3)	28 (12.1)	15 (6.5)	230 (100)
TOTAL	318 (68.2)	79 (16.9)	69 (14.8)	466 (100)

Concerning the year of exposure beginning, 315 cases (67.5%) began exposure between 1926 and 1960, and 151 cases (32.4%) between 1961 and 1988. Looking at the percentages by year of exposure beginning, for the 1926-1960 and 1961-1988 periods, the most represented jobs were naval engineers, etc., motor mechanics, machine captains, and sailors (Table 3).

The distribution by year of incidence shows 87 cases (18.6%) incidents in the years 1993-2000, 231 (49.5%) in the period 2001-2010 and 148 (31.7%) cases in the years 2011-2018. In 2001-2010 all the jobs (except for motor mechanics, captain officer deck, machine captains, various service on ground and wireless radio operator etc.) had an incidence greater than 50% (Table 4).

4. Discussion

Our data agree with what is reported in the literature regarding the risk of mesothelioma for maritime workers regardless of the merchant marine or navy sector and the ship compartment or job performed on board [10, 14-21, 23-39]. Our cases had often worked in the Italian Navy, Merchant, or both. In each of the six specific tasks, more than 50% of the cases had certain exposure (Table 1). The most frequent jobs among our patients were 96 naval engineers etc. (20.6%), 81 motor mechanics (17.3%), 57 sailors (12.2%), and 51 (10.9%) machine captains (Table 2).

Although the earlier cancer-causing risk factors have been eliminated from newer ships, older ships with apparent work-related cancer risks, including asbestos, are still sailing as secondhand ships. Engine room crews were considered to have experienced higher asbestos exposure intensity than other crew members.

However, the distribution of cases with certain exposure among all 23 jobs (Table 2) is consistent with previously published papers [18, 20] confirming that, unlike other occupations, seamen were continually exposed to asbestos while at sea by living onboard ships and from continual release of asbestos fibers due to the motion of the vessels [10, 47].

Concerning our results about the beginning years of exposure (Table 3) was from 1926 to 1988, it must be remembered that the start of the reclamation of ships, as reported in the literature, the reduction and or elimination of asbestos use in ship construction (both merchant and naval) starting in the 1970s and during the mid-1980s [5] with various timescales in different countries. Asbestos was widely used by the Navy during World War II in shipbuilding and continued until the 1980s. In general, asbestos has been used in shipbuilding since the 1880s [48] and was prohibited in 1986 in Denmark but was used under special circumstances until 2005 [25]. Asbestos was removed from all Norwegian Naval ships in the 1980s [23-24]. The U.S. Navy ceased using asbestos-containing thermal insulation in the 1970s [8].

In general, on all ships starting from 1 January 2011, regardless of the nation whose flag the ship flies, new installation of materials that contain asbestos was prohibited according to the International Maritime Organization (IMO) that updated the International Convention for the Safety of Life at Sea

Table 2. Distribution of cases by task, job, and exposure (jobs with less than 5 cases are grouped under other jobs).

		Exposure											
		Certain			Probable			Possible			Total		
Job	Task	N	% by job	% by qualitative exposure	N	% by job	% by qualitative exposure	N	% by job	% by qualitative exposure	N	% by job	% by TOTAL JOB
Maritime Sailor	1	31	54.3	9.7	11	19.2	13.9	15	26.3	21.7	57	100	12.2
Motor Mechanics	6	67	82.7	21.06	9	11.1	11.3	5	6.1	7.2	81	100	17.3
Captains Officers Deck	1	15	57.6	4.7	5	19.2	6.3	6	23.07	8.6	26	100	5.5
Machine Captains	6	42	82.3	13.2	5	9.8	6.3	4	7.8	5.7	51	100	10.9
Naval Engineer, Stoker Charcoal Burner, Tubist	6	78	81.25	24.5	13	13.5	16.4	5	5.2	7.2	96	100	20.6
Electricians	3	21	80.7	6.6	3	11.5	3.7	2	7.6	2.8	26	100	5.5
Carpenters, Welders, Pipe Workers	3	9	64.2	2.8	4	28.5	5.06	1	7.1	1.4	14	100	3.0
Boatswain Boatman	1	7	53.8	2.2	1	7.6	1.2	5	38.4	7.2	13	100	2.7
Various Services	3	3	33.3	0.9	4	44.4	5.06	2	22.2	2.8	9	100	1.9
Kitchen Staff	4	6	50.0	1.8	4	33.3	5.06	2	16.6	2.8	12	100	2.5
Waiters	4	4	66.6	1.2	2	33.3	2.5		-		6	100	1.2
Mooring Diver Pilot Port Toolmaker	5	3	50.0	0.9	1	16.6	1.2	2	33.3	2.8	6	100	1.2
Various Services on the Ground	3	1	16.6	0.3	1	16.6	1.2	4	66.6	5.7	6	100	1.2
Steward, Quartermaster	4	4	50.0	1.2	2	25.0	2.5	2	25.0	2.8	8	100	1.7
Ship's Boy	3	6	66.6	1.8	1	11.1	1.2	2	22.2	2.8	9	100	1.9
Porter Loading Unloading Loading Unloading Officer	3	6	85.7	1.8	1	14.2	1.2		-	-	7	100	1.5
Wireless Radio, Gyroscope, Radio Telemetry, Radar	1	9	40.9	2.8	5	22.7	6.3	8	36.6	11.5	22	100	4.7
Gunner, Torpedo Gunsmith Torpedo Driver Blaster	1	5	55.5	1.5	4	44.4	5.06		-	-	9	100	1.9
Other Jobs	16	1			3			4			8	100	

Table 3. Distribution of cases by job and year of exposure beginning (jobs with less than 5 cases are grouped under other jobs).

	1926-1960			1961-1988			TOTAL	
Job	**N**	**% by job**	**% y since 1st exposure**	**N**	**% by job**	**% y since 1st exposure**	**N**	**% by job**
Maritime Sailor	38	66.6	12.06	19	33.3	12.5	57	100
Motor Mechanics	54	66.6	17.1	27	33.3	17.8	81	100
Captains Officers Deck	16	61.5	5.07	10	38.4	6.6	26	100
Machine Captains	34	66.6	10.7	17	33.3	11.2	51	100
Engineer, Stoker, Charcoal Burner, Tubist	66	68.7	20.9	30	31.2	19.8	96	100
Electricians	20	76.9	6.3	6	23.07	3.9	26	100
Carpenters Iron Welders Pipe Workers	7	50.0	2.2	7	50.0	4.6	14	100
Helmsman Boatswain Boatman	11	84.6	3.4	2	15.3	1.3	13	100
Various Services On Board	5	55.5	1.5	4	44.4	2.6	9	100
Kitchen Staff Cooks	8	66.6	2.5	4	33.3	2.6	12	100
Waiters	4	66.6	1.2	2	33.3	1.3	6	100
Mooring Diver Tugboat Pilot Port Toolmaker	5	83.3	1.5	1	16.6	0.004	6	100
Various Services On The Ground	4	66.6	1.2	2	33.3	1.3	6	100
Steward, Quartermaster	6	75.0	1.9	2	25.0	1.3	8	100
Ship's Boy	7	77.7	2.2	2	22.2	1.3	9	100
Porter Loading Unloading Loading Unloading Officer	2	28.5	0.6	5	71.4	3.3	7	100
Wireless Radio, Gyroscope, Radio, Telemetry, Radar	15	68.1	4.7	7	31.8	4.6	22	100
Gunner, Torpedo Gunsmith Torpedo Driver Blaster	8	88.8	2.5	1	11.1	0.004	9	100
Other Jobs	5	-	-	3	-	-	8	100

(SOLAS), with exceptions for those build before 2011. According to this convention, many ships still contain limited amounts of asbestos. However, "asbestos free" in one country does not necessarily mean the same in another, and so, with long global supply chains, fibers are often found. Depending on where a ship is registered, it will also have that country's standards to abide by. If a ship was built before 2002, it may contain asbestos, so the risks must be considered. A ship built between 2002 and 2011 might have the asbestos materials removed within three years. A ship built in or after 2011 might not contain asbestos. In some vessels certified as "asbestos-free", dangerous materials have been found on board due to repairs carried out in shipyards or purchases of spare parts after the issuance of such certification. Asbestos will have a significant entry path into the vessels through shipyard repairs or purchases of spare parts in countries that are not Member States of the IMO or whose national laws do not control the use of these materials [49, 50].

In Italy, the ban on the use of asbestos dates back to 1992 when the Ministerial Decree of 20 August 1999 imposed the obligation, within a year from its entry into force, to carry out the remediation or mapping and safety, of materials containing asbestos present on Italian ships built before 28 April 1994 or otherwise purchased abroad before that date (IPSEMA the Italian Institute of Insurance for the maritime sector) [51].

Table 4. Distribution of case by job and year of incidence (jobs with less than 5 cases are grouped under other jobs).

	1993-2000			2001-2010			2011-2018			TOTAL	
Job	**N**	**% by job**	**% by incidence year**	**N**	**% by job**	**% by incidence year**	**N**	**% by job**	**% by incidence year**	**N**	**% by job**
Maritime Sailor	6	10.5	6.8	33	57.8	14.2	18	31.5	12.1	57	100
Motor Mechanics	19	23.4	21.8	34	41.9	14.7	28	34.5	18.9	81	100
Captains Officers Deck	7	26.9	8.04	7	26.9	3.03	12	46.12	8.1	26	100
Machine Captains	11	21.5	12.6	21	41.1	9.09	19	37.2	12.8	51	100
Naval Engineer Naval Stoker Naval Charcoal Burner Naval Tubist	21	21.8	24.1	52	54.1	22.5	23	23.9	15.5	96	100
Electricians	4	15.3	4.5	14	53.8	6.06	8	30.7	5.4	26	100
Carpenters Iron Welders Pipe Workers	1	7.1	1.1	7	50.0	3.03	6	42.8	4.05	14	100
Helmsman Boatswain Boatman	3	23.07	3.4	7	53.8	3.03	3	23.07	2.02	13	100
Various Services On Board	1	11.1	1.1	5	55.5	2.1	3	33.2	2.02	9	100
Kitchen Staff Cooks	3	25.0	3.4	8	66.6	3.4	1	8.3	0.6	12	100
Waiters			-	4	66.6		2	33.3	1.3	6	100
Mooring Diver Tugboat Pilot Port Toolmaker			-	4	66.6	1.7	2	33.3	1.3	6	100
Various Services On The Ground	3	50.0	3.4	2	33.3	0.8	1	16.6	0.6	6	100
Steward, Quartermaster	1	12.5	1.1	4	50.0	1.7	3	37.5	2.02	8	100
Ship's Boy	1	11.1	1.1	5	55.5	2.1	3	33.3		9	100
Porter Loading Unloading Loading Unloading Officer	1	14.2	1.1	4	57.1	1.7	2	28.5	1.3	7	100
Wireless Radio Operator Gyroscope Operator Radio Operator Telemetry Operator Radar Operator	2	9.09	2.2	8	36.3	3.4	12	54.5	8.1	22	100
Gunner, Torpedo Gunsmith Torpedo Driver Blaster	3	33.3	3.4	6	66.6	2.5		-	-	9	100
Other Jobs				6			2			8	100

The data reported in the literature indicate that background airborne asbestos concentrations onboard from at least 1978 until 1992 were very low. However, many historical measurements exceeded the OSHA 8-h time-weighted average (TWA) permissible exposure limit (PEL) of 0.1 fibers/cc. Average fiber concentrations generally did not exceed historical occupational exposure limits in place. Still, measurements made during maintenance and replacement of panels or asbestos materials were excluded [2,9]. It is common for merchant seamen to make in-route repairs on asbestos-containing equipment. Airborne asbestos concentrations aboard merchant ships were found to be 51 f/cc for most short-term repair and maintenance tasks [5].

It should be remembered that the OSHA (Occupational Safety Health Administration) PELs (permissible exposure limit) values in the years 1971-1994 were gradually reduced from 12f/cc in 1971 to 0.1 f/cc in 1994 as an eight h TWA (time-weighted average). Moreover, it was demonstrated that once asbestos fibers are disturbed or released into the environment, they can continuously be re-entrained into the air in confined spaces until removed or contained [52]. This can have clear implications for the exposure of sailors in confined spaces at sea while underway, both because asbestos-containing ships are still in service and because sailors both work and live at their worksite 24 h per day, 7 days a week, and are at risk of exposure to asbestos throughout this time, making asbestos standards and permissible exposure limits (PELs) based on an 8-h workday and a 5-day work week inadequate to protect sailors' health [10].

Data on environmental measurements of asbestos published on Italian ferries [53, 54] were within the limits of the law.

Concerning the type of ship where the cases had worked, for those who have been exposed in the Navy, it was possible to reconstruct the type, the date of launch, the date of reclamation, and that of radiation; for those exposed in the merchant navy, the description of the navigation was not present in all cases (type, unit name, company name, Italian or foreign flag, type of navigation, etc.), nor it was possible to trace the information on the AMINAVI database (http://www.aminavi.cnr.it) [55-57].

It should be noted that the Navy has provided for the remediation of naval units that entered service before 1992, starting with the mapping of the presence of asbestos; as of 2020, of the 167 mapped units with permanent crew on board, including naval vessels up to port tugs, the reclamation activities involved 156 units, of which 147 units were reclaimed based on the initial reference mappings, barring the widespread elements; 9 units were initially partially reclaimed, and the completion of the activity will be carried out together with those for the remaining 11 units. The control activity and any further reclamation actions are, therefore, continuous, and any residual asbestos present is contained by encapsulation in compliance with the regulations in force on the subject, thus avoiding risks for personnel (https://www.marina.difesa.it/media-cultura/press-room/comunicati/Pagine/2020_02.aspx 09/01/2020).

However, it should be emphasized that between 1936 and 1992, 79.6% of the MM cases presented here ceased to be embarked and, therefore, exposed. Out of 85 navy ships in our case study, 11 were decommissioned after 1992, 12 were in service after 1992, 7 with complete reclamation, and 5 with partial reclamation.

Limitations of this study are in the type of data on exposure which, typical of a register, is qualitative and not quantitative data, as well as in the lack of reconstruction of the types of ships on which the cases of MM with exposure in merchant marine were embarked, dry cargo vessels, smaller ships, passenger ships, tankers and gas tankers, etc. that could be used as proxies for defining exposures to potential carcinogens. Moreover, a risk of misclassifying exposure may exist because overlap is common between different job departments or positions. In conclusion, as reported by the United States Maritime Commission, "Long after the vessel has been put to sea, flaking and cracking due to ship motions and vibrations are suspected of releasing asbestos into the surrounding space," and "In the course of a voyage it is not unusual for crewmen to repair pipes, pipe flanges, or valve leaks and this generally means a teardown situation. We must assume then that machinery and piping asbestos insulation affects not only the shipyard worker but also the crew under various conditions." [58].

Maritime work is developed internationally concerning the elements that make up the operation and manpower of the vessel. Despite this, seafarers may be under-protected with regards to ensuring their occupational health and safety while working on board because the protection of health and safety at work derived from the European Union, the International Maritime Organization, and the International Labor Organization present limitations in the application of health surveillance to seafarers [59, 60]. Ships, both as workplaces and as living spaces, have special conditions of habitability, as well as irregular environmental conditions and risk factors (such as noise, vibrations, air temperature, humidity, asbestos, and various carcinogens exposure) [61, 62]. It would be desirable for seafarers exposed in the past to be guaranteed health surveillance since many vessels built before and until at least the 80s contained asbestos materials.

Epidemiological surveillance on MMs, through the National Mesothelioma Register has allowed us to verify among cases with exclusive exposure in the maritime, navy, and merchant marine sectors that subjects with the beginning of exposure in the years 1926-1988 were all asbestos-exposed regardless of the ship's department where have provided service therefore, as already reported in the literature [37], these cases must all be considered as occupational diseases.

Institutional Review Board Statement: In Italy, malignant mesothelioma reporting to the national Registry is compulsory by law (Legislative Decree 9 April 2008, no. 81, art. 244); therefore, ethics approval is not required.

Declaration of Interest: The authors declare no conflict of interest.

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Supplementary Material

Table 1S. Maritime workers' professional qualifications by task and job.

TASK	JOB
1. Deck Crew	Cabin Boy, Deck Boy, Marine Sailor, Tankman, Deck Worker, Tractor Driver, Cabinetmaker, Shipwright Carpenter, Gun Master, Boatswain, Brass Worker, Deck Worker, Pilot, Technical Ship Inspector, Deck Officer, Captain , Accountant, Secretary, Interpreter, Bank Clerk, Guard Chief, Ticket Seller, Welder Autogenist, Inspector, Radio Operator, Telephonist, Wireless Operator, Signalman Chief, Helmsman, Bridge Crane Operator, Elevator Operator, Cashier, Cashier, Light Operator, Sentryman, Plumber, Dressing Room, Inspector, Supercargo, Auctioneer Sailor, etc.
2. Healthcare Personnel On Board	Nurse, Physician, etc.
3. Multi-Purpose Staff - Various Service Personnel	Multi-Purpose Worker, Printer, Cinematographer, Office Assistant, Stewardess, Beautician, Manicurist, Hairdresser, Barber, Gymnast, Orchestral Player, Social Entertainer, Salesman, Purser, Cabinet Maker, Carpenter, Storekeeper, etc.
4. Kitchen, Room Staff And Family	Kitchen Boy, Cook, Sub-Head Cook, Head Chef, Crew Cook, Steward, Pastry Chef, Steward, Bottler, Housekeeper, Baker, Butcher, Launderer, Ironer, Head Hors D'oeuvres, Head Pantry Steward, Head Legume, Etc Errand Boy, Footman, Commis, Cabin Steward, Lounge Steward, Porter, Head Of Quarters, Cloakroom Attendant, Butler, Nanny, Bartender, Night Watchman, Baggage Master, Cabin Boy, Etc.
5. Personnel In Charge Of Local Traffic And Coastal Fishing	Pilots, Maritime Surveyor, Mooring Men, Naval Engineering Technicians, Port Maintenance And Engineering Technicians, Divers, Divers, Boatmen, Fishing Chief, Practical, Net Fixer, Nets, Boat Master, Rower, etc.
6. Machine Crew	Brasssmith, Engineer, Refrigeration Engineer, Engine Engineer, Electrician, Mechanic, Stoker, Engineer Officer, Chief Engineer, Electrical Engineer, Autogenista Welder, Fitter, Carpenter, Tanker, Welder, Brazer, Boilermaker, Coalman, Foreman, Greaser, etc.

Table 2S. Maritime workers by jobs, task and ISTAT Professional Code.

Job	Task	ISTAT code ReNaM ISTAT Professional Code
Maritime Sailor	1	74511, 74510, 74590,
Motor Mechanics	6	74527, 62316, 623113, 623112, 62231,74520,74524, 62314, 62316
Submariners	6	31611, 74590
Captains Officers Deck	1	312610, 900015, 900019, 900030, 900039, 900069, 900076, 31261, 312610, 312611, 312617,
Machine Captains	6	312613, 312618, 31267, 312613, 312618, 31260,
Naval Engineer Naval Stoker Naval Charcoal Burner Navaltubist	6	74523, 74526, 74351, 74522,74520,74524, 732832, 863218, 74521, 62194
Electricians	3	624112, 74549,
Carpenters Iron Welders Pipe Workers	3	61234, 62142, 74545, 74540
Wood Carpenter	3	74545, 652214, 74540
Helmsman Boatswain Boatman	1	74518, 900025, 74514, 74530,
Various Services On Board	3	251613, 31215, 41298, 63411,
Kitchen Staff Cooks	4	522111, 52291, 74594,
Waiters	4	52230, 522310, 522315, 52234, 52192
Engineering Technicians, Refrigeration Engineer, Naval Plumbers Etc	1	22194, 6234
Mooring Diver Tugboat Pilot Port Toolmaker, Etc	5	62162, 74537, 312615, 74516, 74543, 6216
Various Services On The Ground	3	33433, 81110, 81298, 251613
Steward, Quartermaster	4	74594
Unqualified Personnel Cleaning	3	81410
Firefighters	3	56141
Ship's Boy	3	74517, 82214
Porter Loading Unloading Loading Unloading Officer	3	81214,
Wireless Radio Operator Gyroscope Operator Radio Operator Telemetry Perator Radar Operator	1	312414, 312421, 422411, 42245, 42249, 631918, 63198, 63198,
Gunner, Torpedo Gunsmith Torpedo Driver Blaster	1	51221, 63116

Table 3S. Navy vessels on which MM cases have been embarked according to ship's logs.

NAME	TYPE	YEAR LAUNCHED	YEAR REMEDIATION	YEAR REMOVAL	CREW
ALBENGA	TUGS FOR LOCAL AND PORT USE	1942	NO	1990	????
AIRONE	ANTI-SUBMARINE CORVETTES	1954	NO	1992	117
ALCIONE	ANTI-SUBMARINE CORVETTES	1954	NO	1992	117
ALDEBARAN	CLASS ESCORT ALERTS	1943	NO	1975	189
ALPINO	ANTI-SUBMARINE FRIGATES	1967	INCOMPLETE	2006	264
ANCONA	EXPLORER SHIP	1912	NO	1937	442
ANDREA DORIA	MISSILE CRUISERS AND HELICOPTER CARRIERS	1963	NO	1992	500
ANDROMEDA	CLASS ESCORT ALERTS	1943	NO	1971	189
APE	ANTI-SUBMARINE CORVETTES	1942	NO	1979	112
BAFILE	SHIP FOR TRANSPORTING TROOPS AND MATERIALS	1943	INCOMPLETE	1981	118
BRACCO	SUPPORT GUNNER	1944	NO	1974	1984
CADORNA	LIGHT CRUISERS	1931	NO	1951	507
CAIO DUILIO	MISSILE CRUISERS AND HELICOPTER CARRIERS	1962	NO	1990	500
CANOPO	CLASS ESCORT ALERTS	1955	NO	1984	235
CAPPELLINI	SUBMARINES	1944	NO	1977	74
CARABINIERE	ANTI-SUBMARINE FRIGATES	1971	INCOMPLETE	2008	264
CASSIOPEA	OFFSHORE MARITIME PATROL VESSELS	1988	2012	2022 in service	60
CASTORE	CLASS ESCORT ALERTS	1956	NO	1980	235
CAVEZZALE	SUPPORT SHIP DARING RAIDERS	1942	INCOMPLETE	1994	114
CENTAURO	FRIGATE	1954	NO	1984	235
GIULIO CESARE	BATTLE SHIPS	1914	NO	1948	1000
CHIMERA	ANTI-SUBMARINE CORVETTES	1943	NO	1971	112
CICLOPE	LARGER TUGS	1984	INCOMPLETE	2022 in service	??
CIGNO	CLASS ESCORT ALERTS	1955	NO	1982	235
CLIO	TORPEDO BOAT ESCORTS	1938	NO	1959	99
DUCA D'AOSTA	LIGHT CRUISERS	1934	NO	1949	578

Table 3S (*Continued*)

NAME	TYPE	YEAR LAUNCHED	YEAR REMEDIATION	YEAR REMOVAL	CREW
DUILIO	MISSILE CRUISERS AND HELICOPTER CARRIERS	10962	INCOMPLETE	1990	500
DV 408	FAST MINESWEEPERS	1945	NO	1965	24
EBANO	COASTAL NON-MAGNETIC MINESWEEPERS	1956	INCOMPLETE	1989	38
ETNA	LANDING TRANSPORT SHIP	1944	INCOMPLETE	1977	120
FAGGIO	COASTAL NON-MAGNETIC MINESWEEPERS	1952	INCOMPLETE	1980	38
FIUME	HEAVY CRUISER	1929	NO	1941	841
FLORA	ANTI-SUBMARINE CORVETTES	1942	NO	1969	112
FOLAGA	ANTI-SUBMARINE CORVETTES	1942	NO	1965	112
GAGGIA	COASTAL NON-MAGNETIC MINESWEEPERS	1955	NO	1980	38
GARIBALDI	AIRCRAFT CARRIER CRUISER	1983	1990-2022	in service	825
GAZZANA	SUBMARINES	1944	NO	1981	87
GLICINE	COASTAL MINESWEEPER	1956	NO	1980	38
GRECALE	MISSILE FRIGATES	1981	INCOMPLETE	2020	225
GRU	ANTI-SUBMARINE CORVETTES	1943	NO	1970	112
IMPAVIDO	DESTROYER	1962	NO	1991	333
IMPETUOSO	DESTROYER	1956	NO	1983	335
INDOMITO	DESTROYER	1955	NO	1983	335
INTREPIDO	DESTROYER	1962	NO	1991	333
LIBRA	OFFSHORE MARITIME PATROL VESSELS	1988	2012	2022 in service	60
LUIGI DI SAVOIA	MISSILE CRUISERS AND HELICOPTER CARRIERS	1936	NO	1961	640
LUPO	MISSILE FRIGATES	1976	INCOMPLETE	2004	185
MANGO	COASTAL NON-MAGNETIC MINESWEEPERS	1956	INCOMPLETE	in service	38
MARE CHIARO	GUNBOAT	1903	NO	1943	68
MAS 521	ANTI-SUBMARINE MOTORBOAT	1937	NO	1950	9
MINERVA	ANTI-SUBMARINE CORVETTES	1942	NO	1969	112
MIRTO	COASTAL NON-MAGNETIC MINESWEEPERS	1954	INCOMPLETE	2000	38

NAME	TYPE	YEAR LAUNCHED	YEAR REMEDIATION	YEAR REMOVAL	CREW
MOC	MOTO-OFFICINE COSTIERE	1943	2010	2000	26
MONTECUC-COLI	LIGHT CRUISERS	1934	NO	1964	578
NOCE	COASTAL NON-MAGNETIC MINESWEEPERS	1953	INCOMPLETE	1983	38
OLMO	COASTAL NON-MAGNETIC MINESWEEPERS	1953	INCOMPLETE	1983	38
ORIONE	OFFSHORE MARITIME PA-TROL VESSELS	2002	*"asbestos-free"*.	2022 in service	54
ORSA	MISSILE FRIGATES	1979	INCOMPLETE	2004	185
PALINURO	SAILING SCHOOL SHIP	1934	2010	2022 in service	2+72
PINO	COASTAL NON-MAGNETIC MINESWEEPERS	1953	INCOMPLETE	in service	38
PIOMARTA	SUBMARINES	1951	NO	1986	82
PLATANO	COASTAL NON-MAGNETIC MINESWEEPERS	1954	INCOMPLETE	1981	38
POMONA	ANTI-SUBMARINE CORVETTES	1942	NO	1965	112
PROTEO	SUPPORT AND RESCUE VESSELS	1951	NO	1993	118
SAETTA	GUNBOAT	1966	NO	1986	36
SAGITTARIO	MISSILE FRIGATES	1977	INCOMPLETE	2006	185
SAN GIORGIO	EX-LIGHT CRUISER DESTROYERS	1941	NO	1965-SCHOOL SHIP	360
SAN MARCO	EX-LIGHT CRUISER DESTROYERS	1941	NO	1971	360
SANDALO	COASTAL NON-MAGNETIC MINESWEEPERS	1957	INCOMPLETE	1988	38
SCIPIONE AFRIC.	LIGHT CRUISERS	1941	NO	1948	418
SIBILLA	ANTI-SUBMARINE CORVETTES	1943	NO	1975	112
STAFFETTA	OFFSHORE MARITIME PATROL VESSELS	2002	*"asbestos-free"*.	2022 in service	14
STEROPE	TEAM LOGISTICS SHIP	1944	NO	1975	??
STROMBOLI	TEAM LOGISTICS SHIP	1975	NO	2022 in service	124
VESPUCCI	SAILING SCHOOL SHIP	1931	2010	2022 in service	22+421

Table 3S (*Continued*)

NAME	TYPE	YEAR LAUNCHED	YEAR REMEDIATION	YEAR REMOVAL	CREW
VESUVIO	TEAM LOGISTICS SHIP	1943	NO	2023 in service	??
VISCHIO	COASTAL NON-MAGNETIC MINESWEEPERS	1956	INCOMPLETE	in service	38
VITTORIO VENETO	MISSILE CRUISERS AND HELICOPTER CARRIERS	1967	INCOMPLETE	2000	560
ZEFFIRO	MISSILE FRIGATES	1984	INCOMPLETE	2022 in service	225