UNIVERSITÀ DEGLI STUDI DI TRIESTE

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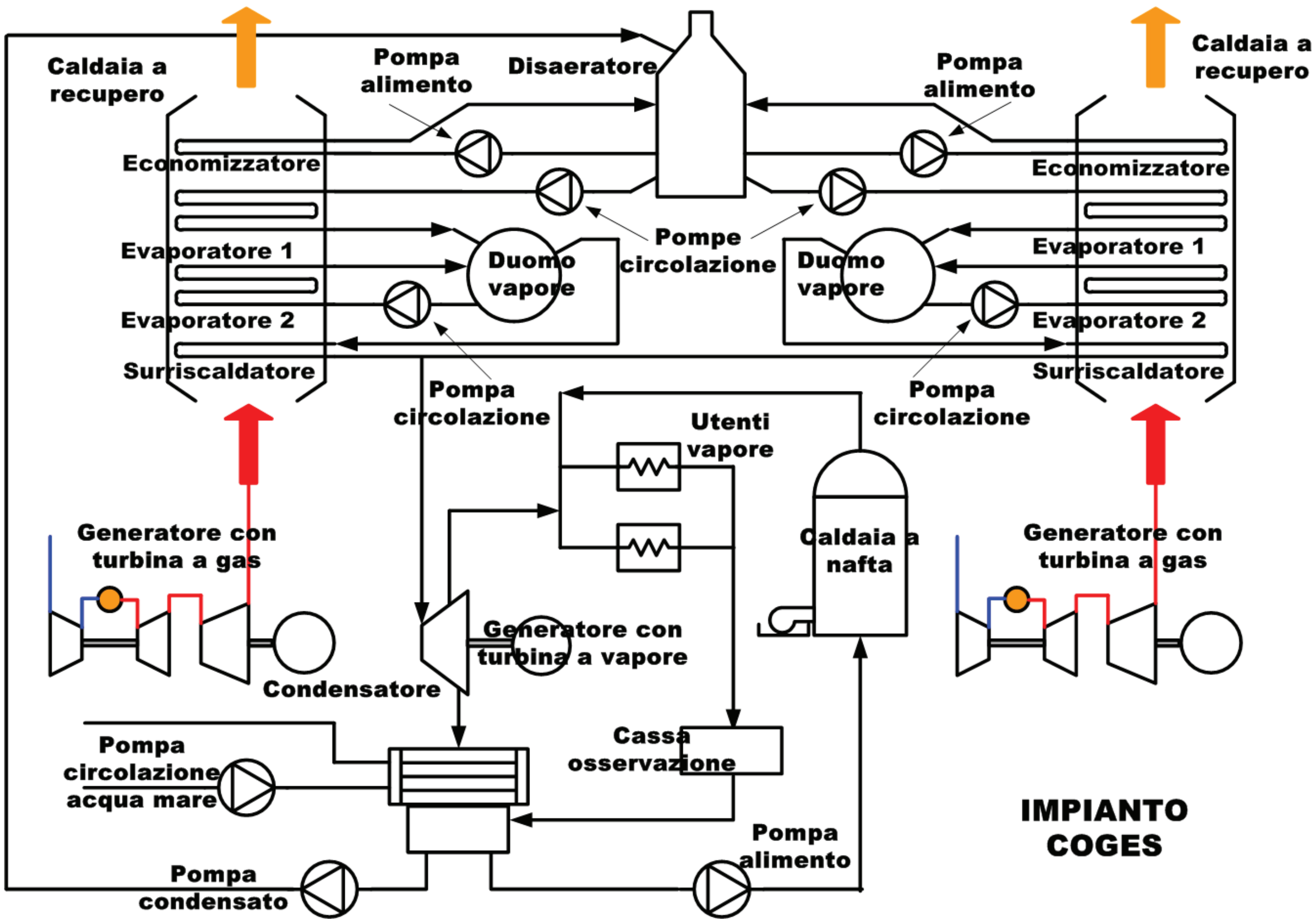
Progetto di impianti di propulsione navale

6.3 APPLICAZIONI NELLA GENERAZIONE

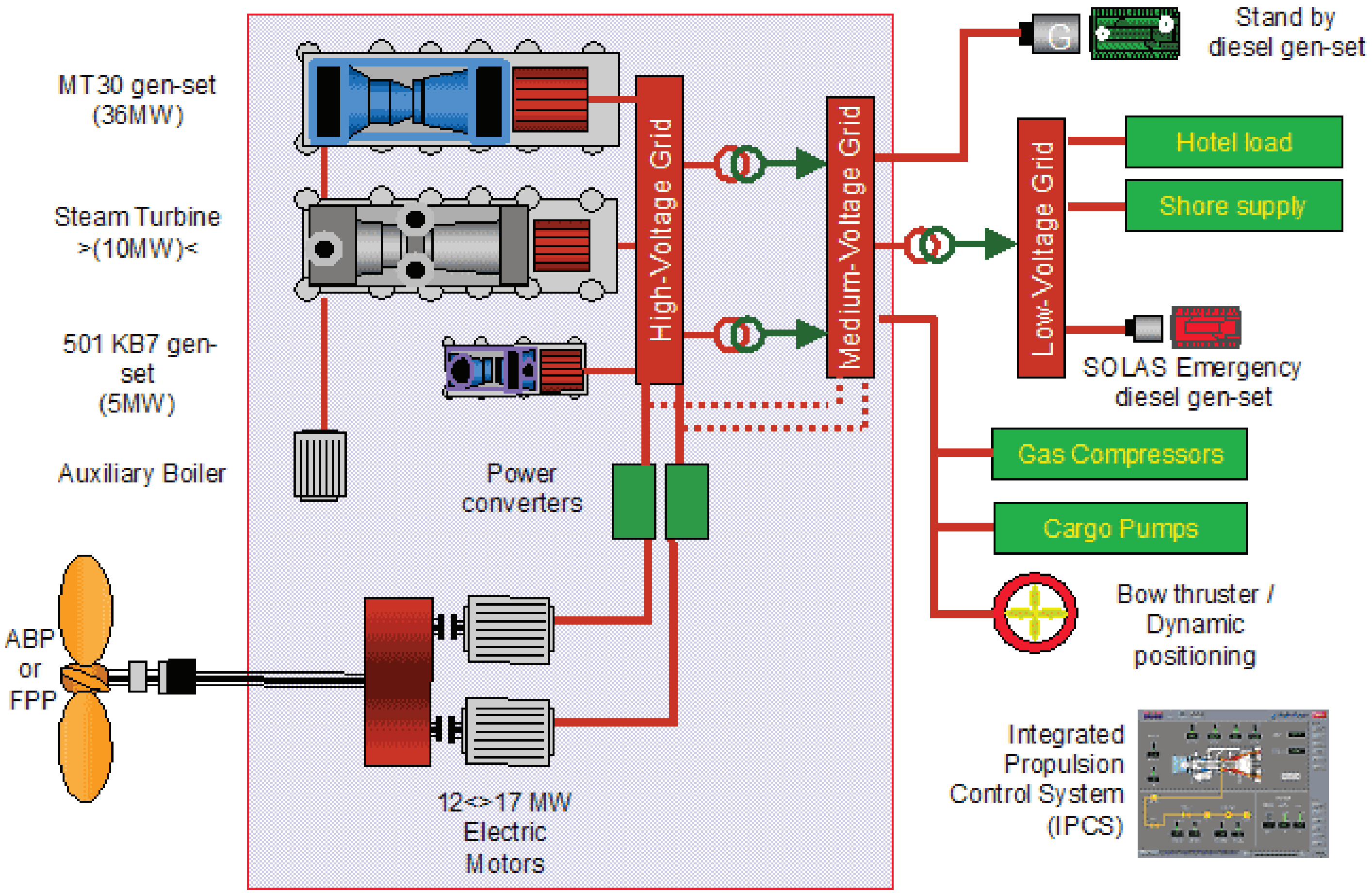
Anno Accademico 2017/2018

Impianti di propulsione navale



Impianti di propulsione navale

Impianto COGES per navi LNG carrier (Rolls-Royce)



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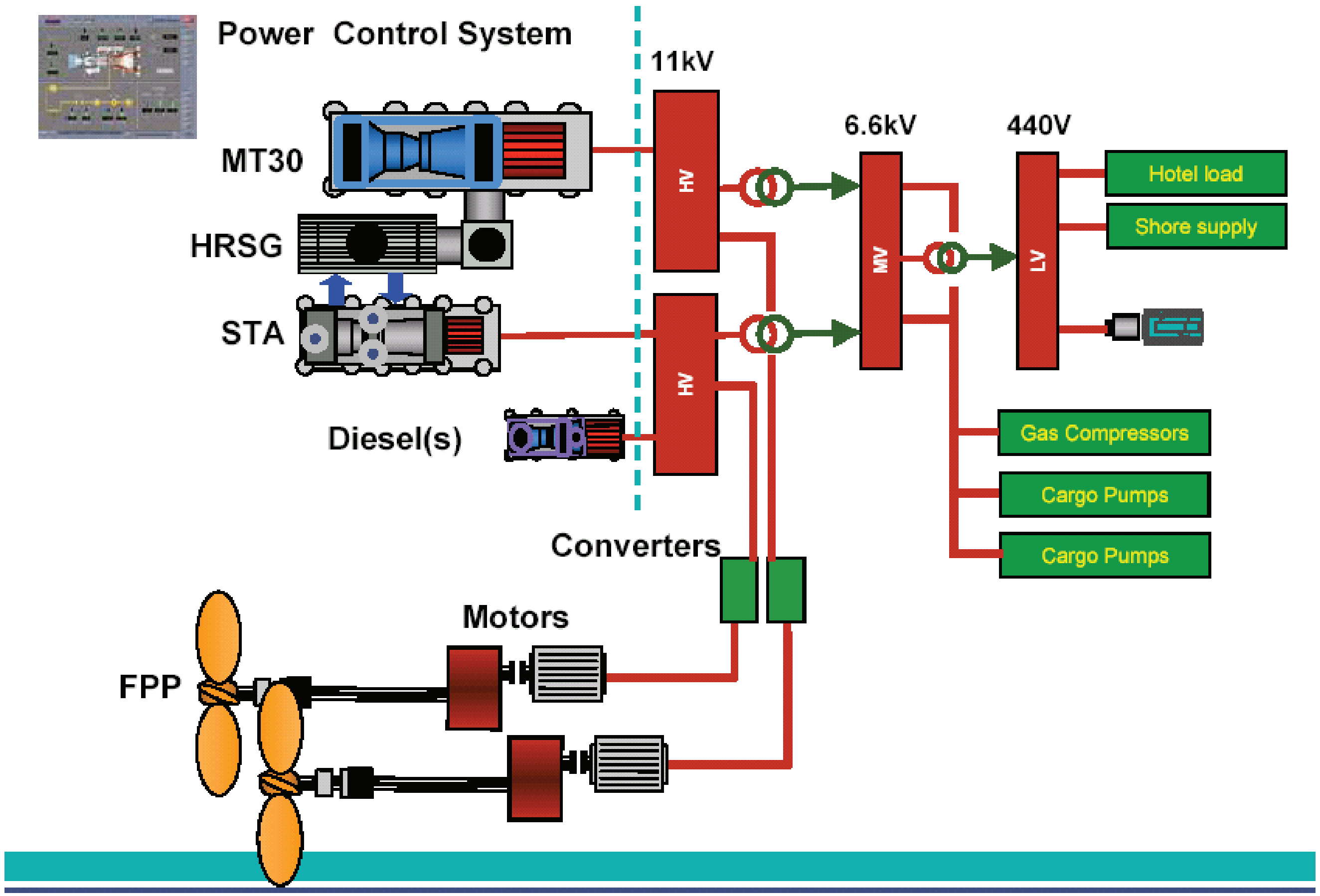
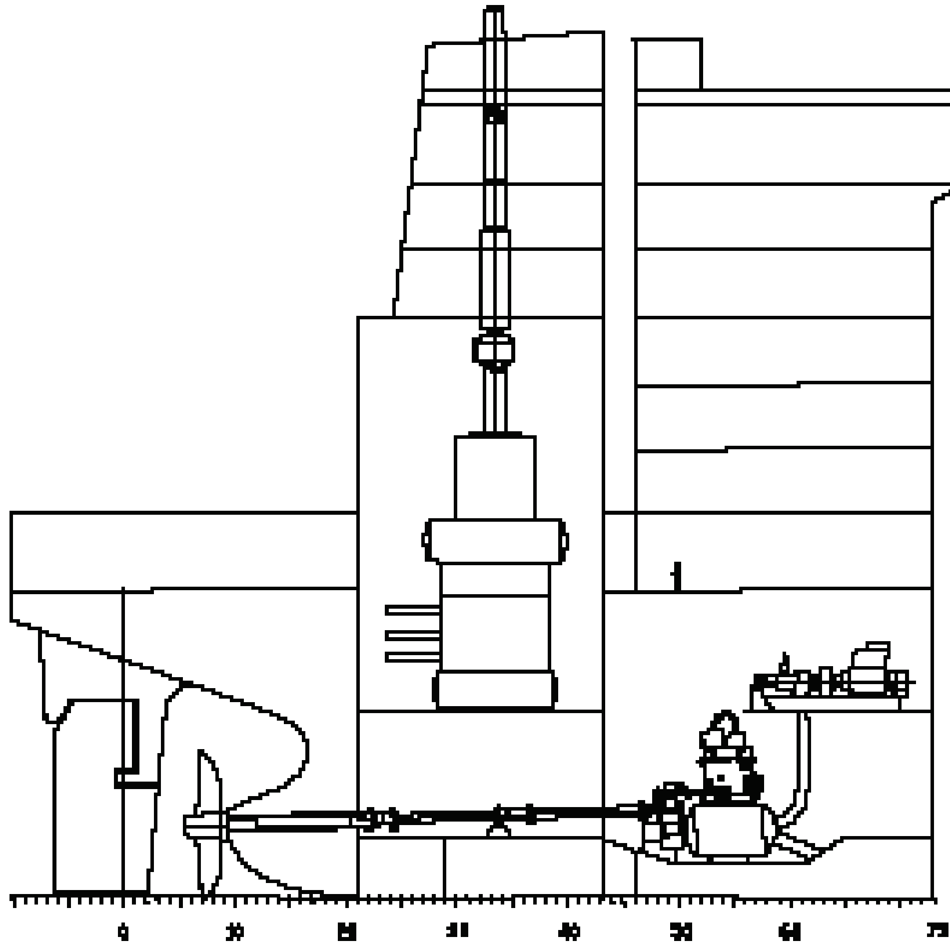


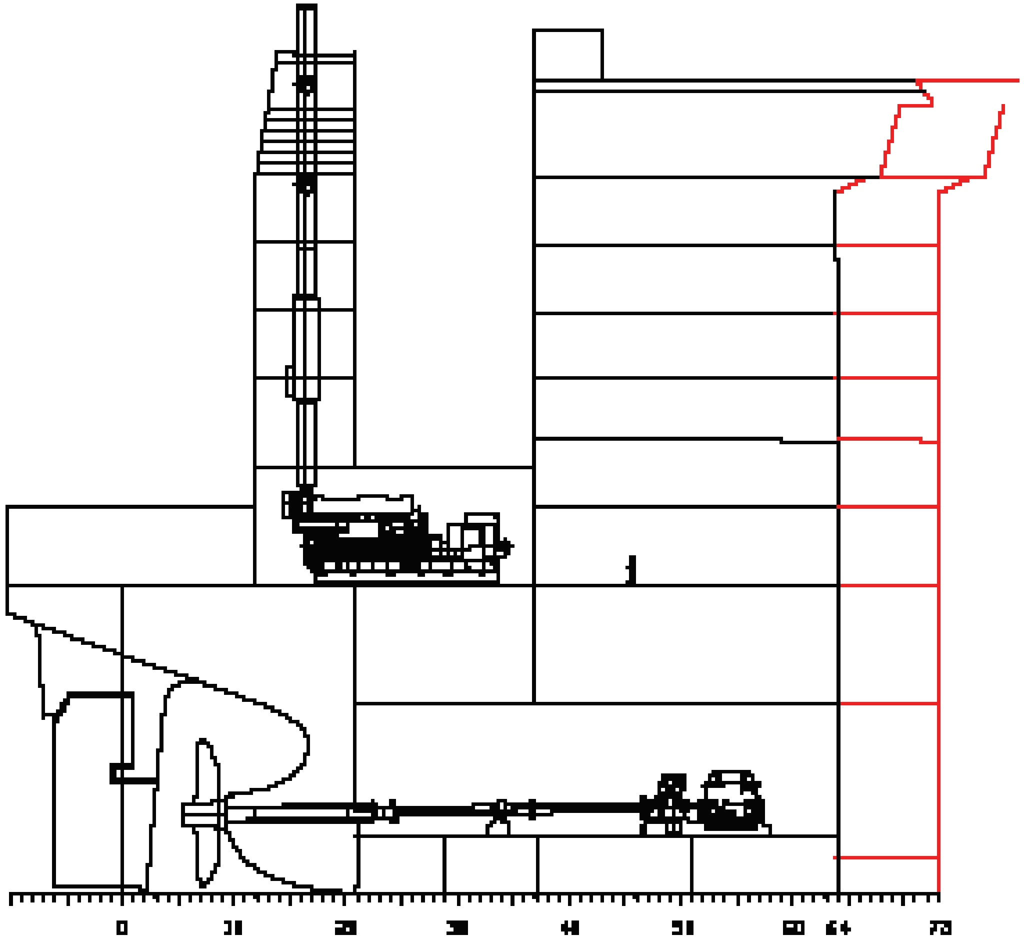
Impianti di propulsione navale

LNG carrier con propulsione a vapore



Impianti di propulsione navale

LNG carrier con propulsione diesel-elettrica “dual fuel”



Impianti di propulsione navale

Il punto di vista di un costruttore di motori diesel (MAN – B&W) sull'applicazione della propulsione COGES nelle navi da crociera

Merits of Diesel Engines and Gas Turbine in Marine Propulsion

A typical diesel-electric drive with five medium-speed diesel engines will be compared with the 58 MW COGES (Combined Gas Turbine and Steam Turbine Integrated Electric Drive System).

In summer 2000, Celebrity Cruises' gas turbine-driven cruising vessel Millennium made her maiden voyage. The 91000 Ton vessel with a Pax capacity of 1950 (lower berth) denotes a technological shift in cruise ship design, primarily because she is the first cruise ship powered by a pure gas turbine plant. Apart from this, the ship has the biggest azimuth pods ever built (two Mermaid pods of 19.5 MW each). Currently there are three further cruise ships of this series under construction. This certainly is a milestone for gas turbine movers, the more so as four further new Vantage-class cruise ships for Royal Caribbean International (RCI) are also specified with turbine-based propulsion plants. Each plant consists of two General Electric LM2500+ aero-derived gas turbines of 25 MW each and an 8 MW back-pressure steam turbine. The steam turbine uses steam from the boilers fired by waste-heat from the gas turbines to generate additional electrical power.

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Diesel engines versus gas turbines.
Pros and cons.

Depending on the amount of steam required for onboard services, the complete COGES power plant is expected to achieve a combined-cycle efficiency of between 45 and 50%.
This system will provide for all onboard power arrangements, such as propulsion, heating, cooling, lighting, ventilation, kitchen and laundry.

Diesel engines versus gas turbines
Pros and cons

MAN B&W

Criteria	diesel engines	gas turbines
Weight and size		✔
Initial costs	✔	
Maintenance costs	✔	
Fuel consumption	✔	
HFO capability	✔	
Part-load operation	✔	
Transient response	✔	
Structure-borne noise		✔
Air-borne noise		✔
L.O. consumption		✔
NO_x emission		✔
SO_x emission		✔
CO_2 emission	✔	
Ambient conditions	✔	

Gas turbine

However, with about 97% of all existing sea-going ships propelled by two and four-stroke diesel engines due to its comparably high thermal efficiency, it seems their manufacturers have so far not seriously been affected by gas turbines in most of their traditional market areas.

In general, diesel engines posses lower initial costs, fuel economy, weight and size as comparing with gas turbine's environmental friendliness

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Weight and size

Gas turbines are known to generate lots of power while offering less space and weight than a diesel engine of the same output.
The diesel engine's size and heavy mass is an undisputable disadvantage in many applications.

However in the new Panamax-sized cruise ships with an increased number of decks but unchanged width, much weight is needed in the bottom of a ship for stability purposes, so the value of the weight savings by gas turbines must not be over emphasized. In order to decrease the vertical center of gravity, this weight deficiency could be compensated by additional fresh water or fuel tanks. Another option is to slightly decrease the main deck height or draught of the vessel. However, all of this would necessitate a new ship design, excluding the use of a common hull form for either diesel engines or gas turbines that would be highly beneficial in order to cut costs.

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Weight and size

As regards the space savings of gas turbines, this potential cannot be fully utilized: gas turbines have approx. 15% larger air intake and exhaust ducts as comparable diesel engines and their starting devices also occupy much space.

On board cruising vessels with two gas turbines as prime movers, necessary provisions for a rapid replacement of a gas turbine (or at least its gas generator) within a few hours, with the vessel at sea and underway, occupies extra space.
The engine room has to be designed with sufficient free space and all the necessary provisions and equipment for this job, including storage space for a complete spare gas turbine.

Finally, plant availability and safety considerations make at least one or two additional diesel engine gensets mandatory to satisfy low power requirements difficult to cover with a gas turbine and as emergency generator.
This does not only restrict the freed space further, but also increases first costs, operating costs and maintenance costs.

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First and maintenance costs

Contrary to weight and size, first costs and maintenance costs are lower for the diesel solution, although first costs might be more a political concession. As regards maintenance, RCI has signed a 10 year repair and maintenance contract with General Electric for the vessels' LM2500+ gas turbines at a cost of 3 $/MW h. The maintenance cost summary of a multi-engine Diesel-electric gives a lower figure.

Fuel and operating costs

Diesel engines enjoy further benefits such as lower fuel prices, lower fuel consumption rates at all loads and therefore lower carbon dioxide emission and better load acceptance as well as quicker start-up times after a night stop. For instance, after a night stop, a gas turbine in simple-cycle mode needs 30 minutes until full load is reached, a diesel engine in the same situation less than 5 minutes.

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Vibration and noise

As regards vibration and noise, multiple cylinder reciprocating engines with their intermittent combustion are at a disadvantage, although sometimes the real differences are exaggerated or erroneously interpreted.
By direct-resilient mounting of Diesel engines, their structure-borne vibration transmitted into a ship foundation is reduced to a level of approximate below 50 dB at frequencies of above 1000 Hz.
Although resiliently seated gas turbines might reach still lower values, design measures aiming at an even further decrease in diesel engines' structure borne noise can be omitted as long as the requirements regarding vibration in the cabins are met.

Unexpectedly, the new-building Millennium experienced vibration problems in some areas of the ship under special sea conditions likely to occur in the Caribbean during the windy winter season. The ship had to be dry-docked for technical modifications earlier than planned, following its arrival in New York in November 2000.

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Air-borne noise

Air-borne engine room noise of gas turbines is claimed to be less than 85 dB(A), whereas the noise emission of a MAN B&W large-bore medium-speed diesel engine varies between 102 and 108 dB(A) at full load.
The main reason for this difference is that marine gas turbines are installed in acoustically insulated enclosures whereas the noise level for free-standing diesel engines is measured without any sound-attenuating encapsulation or lagging.
Engine machine rooms are not among the places where passengers onboard usually spend their leisure time. Therefore the lower running noise of gas turbines is not of major importance: outside of the machine room, the diesel engines can be considered to be encapsulated as well.

Lube oil consumption

The specific lube oil consumption of modern gas turbines is typically only 1% of the diesel engines' figure, but high priced synthetic lubes have to be used in comparison to the low-priced mineral oils for the Diesel engines. The annual lube oil costs of gas turbines are only about 6% of that of diesel engines. It has to be pointed out that this merit is of minor importance, since lube oil costs hardly affect the total operating costs.

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Exhaust gas emissions

The real advantage of the gas turbine is its eco-friendliness as far as SOx and NOx (not CO2) emissions are concerned.

SOx emission of gas turbines is close to zero because they burn basically sulfur-free fuel (MGO typically contains only about 0.3 % sulfur, HFO for diesel engines up to 4.5%). If (higher-priced) low-sulfur or sulfur-free marine diesel oils would be used for diesel engines, there wouldn't be a SOx problem with them either.

There is no basic technical restriction in decreasing diesel engines NOx emission down to a level of 2 g/kWh by adopting SCR based exhaust-gas cleaning. All today's serial NOx optimized marine diesel engines have to meet IMO NOx restrictions for international shipping valid for new ships (achieved by engine -internal measures).

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By direct injection of water into the cylinder or by adopting water-fuel emulsification, a similar NOx emission level as with today's standard marine gas turbines without water injection is achieved.
The test results of a MAN B&W 6L48/60 engine in February 2000: a NOx cycle value of 7.7 g/kWh and a fuel consumption rate still within tolerance (5%) was measured. This is 40% below the NOx limit set by the IMO. This result was achieved with only 15% water in the water-fuel emulsion and a slightly retarded injection below 80% engine load.

NOx emission of marine prime movers
in g/kWh

IMO's NO_x limit value for diesels (400-450 rpm)	13
MAN B&W V 48/60, NO_x-opt.	12
V 48/60, NO_x-opt. + fuel-water emulsion (15-20 %)	8 - 9
Engines with direct water injection (50-60 %)	6
Engines with HAM technology	3 - 4
Engines with SCR (Selective Catalytic Reduction)	2
Marine gas turbines without water injection	5
Gas turbines with water injection	2 - 3

NOx emission levels of modern marine gas turbines and diesel engine.

Engine shop test 6L 48/60 with emulsion injection
containing 15 % of water (const.)

Load, %	25	50	75	85	100
Output, kW	1 575	3 150	4 725	5 355	6 300
SFOC, g/kWh	211.7	202.8	191.8	183.9	184.7
NO_x, g/kWh	6.44	7.08	6.97	10.89	9.58

NO_x cycle value (E2): 7.7 g/kWh

Constant speed 514 rpm
Fuel: MDO
Fuel consumption: ISO 3046-1, LHV 42,700
Test date: 17 February 2000

SFOC and NOx emission levels of a diesel engine utilizing water-fuel emulsion.

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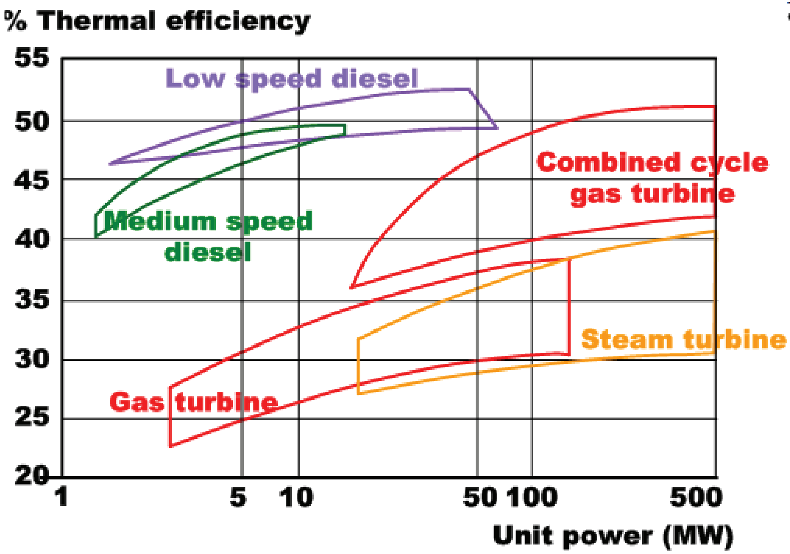
Efficiency

The right figure shows the achievable overall efficiency level of today's prime movers. Large-bore medium-speed engines reach up to 47% in simple-cycle operation and low-speed diesel engines even up to 51%.
With smaller engines the difference in efficiency and in fuel consumption between diesel engines and gas turbines increases considerably.
The figure is indicative of the high efficiency level that combined-cycle gas turbines of high unit output (above 50 MW) reach today.



Up to now there are only few diesel combined-cycle (DCC) installations in operation.
Their number will increase in future although this technology will increase the diesel's efficiency level only by a few percentage points.

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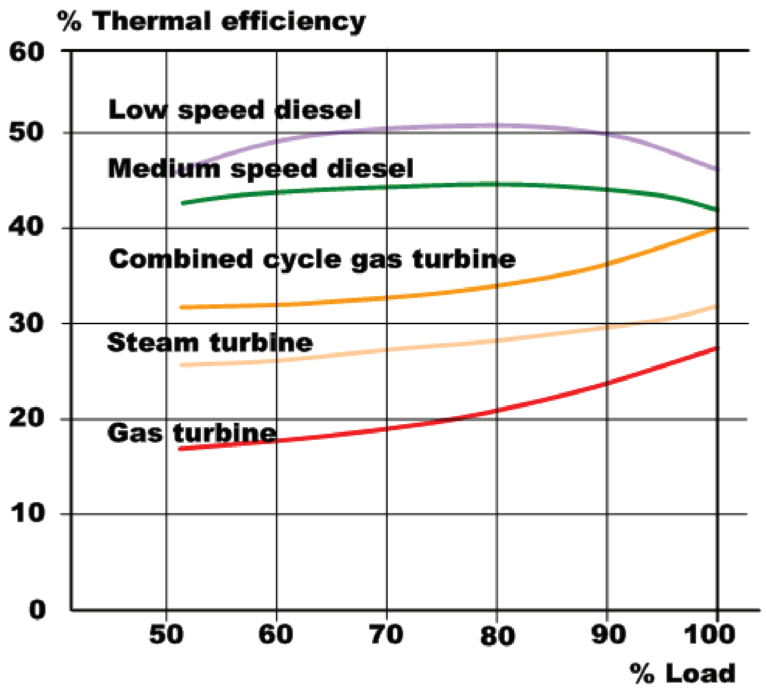
The thermal efficiency over the total power output for the various engine types are plotted in the right diagram.
From 90% load down to approx. 60% load, the thermal efficiency of medium speed diesel engine is almost constant, with a mean SFOC of 190 g/kW h.
Contrary to this favorably flat fuel consumption line, the turbines' consumption rates are highly load dependent.
At very high rate power, COGES has a SFOC of around 210 g/kW h (corresponding thermal efficiency about 40%) which is only slightly higher than that of diesel engines' figure indeed.
However, this high power is hardly used in cruising: most of the time, the turbines have to operate at part load with much higher specific fuel consumption rates.



Si ricorda che :

$$\eta = \frac{3600}{Pci^{kJ/kg} SFOC^{kg/kWh}}$$

Impianti di propulsione navale

Calculation of the annual fuel costs was based on the following typical weekly load scenario:
60 hours per week in ports (power requirement 10 MW): one 12V 48/60 Diesel engine or one gas turbine with the steam turbine in operation.

Annual fuel costs COGES (90 MWel)
vs. diesel-electric (81 MWel) in m US-$

	COGES	diesel-electric
Fuel	MGO	HFO 380 cSt
Fuel price, $/ton*	300	145
Fuel consumption, tons	45,120	39,540
Fuel costs, m $	13.54	5.73
Additional fuel amount for steam production (17 tons/hr), tons	1,000	7,060
Additional fuel costs, m $	0.3	1.03
Total annual fuel costs, m $	13.84	6.76

*) Fairplay August 31, 2000 (fuel prices North West Europe listed August 25, 2000)

This sums up to 3 840 operating hours per year for each of the five diesel engines, and 6 150 hours for each of the two gas turbines.
For this load profile and for average August 2000 fuel prices for North West Europe, the total fuel costs are shown in figure.

The difference in annual fuel costs between COGES and the diesel-electric option is US-$ 7 million.
The costs for the extra fuel burnt in oil-fired boilers for production of the necessary steam amount (17 tons/h) is already included.
COGES needs only little additional fuel for steam production, actually only what is needed during stays in ports.
One of the main reasons for the higher fuel amount of the Diesel-electric power plant used for steam production is that more steam has to be produced by the oil-fired boilers with decreasing numbers of Diesel engines in operation.

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The crucial question is, whether or not the much higher fuel costs of the COGES plant can be compensated by higher revenues from selling (up to) 50 extra twin cabins in the lower decks. Repeatedly, it has been stated from the gas turbine proponents, that "the extra revenue yielded will comfortably offset the higher turbine fuel costs of COGES".
First of all, it cannot be taken for granted that 50 additional twin cabins, plus other new public recreation areas and spaces, are achievable with a comparable ship design, without penalising the passengers' comfort standard.
Consultants outlined that perhaps only half of this amount is realistic, but inspite of these concerns, the claimed number of 50 additional cabins is used for the following economy estimate.
Assuming that 90% of the beds in these 50 extra cabins are always sold, 50 weeks per year, and let for an average of US-$ 200 per person and day (a reasonable rate for small cabins without windows), the additional income is about US-$ 7 million per year. This already includes the turnover yielded by the passengers' personal expenses onboard. Assuming a profit margin of 30%, the overall annual net profit is US-$ 2.1 million (70% are costs of the operators to build and equip the cabins, for food, cabin cleaning, laundry, costs for increased staff, taxes, etc.).

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Commercial result

The total sum of fuel costs and lube oil costs is US-$ 13.86 million for COGES and US-$ 7.04 m for the diesel-electric system. The difference is US-$ 6.8 million per year. With the total annual net profit of only US-$ 2.1 million, it is impossible to compensate higher fuel bill of COGES. With bunker prices in September 2000, there is a loss of US-$ 4.7 million every year and for every ship and this does not include the higher first and maintenance costs.
In comparison to a COGES system, diesel-electric solutions have clear advantages in many aspects, with the exception of weight and size, and NOx emission and noise.

Summary
In comparison to a COGES system, Diesel-electric solutions have clear advantages in many aspects, with the exception of weight and size, and NOx emission and noise. These advantages are:
uniform machinery, lower fuel costs and lower fuel consumptions and therefore lower CO_2 emission, lower first costs, operating costs, easier maintenance, lower maintenance costs and wider operational flexibility and redundancy on account of the larger number of diesel engines that are able to burn widely varying fuel qualities.

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The gas turbine itself, as an intrinsically simple rotating machine, is highly reliable and durable as it has fewer moving parts and lower friction losses, but the more complicated COGES system involving a steam turbine genset had no chance up to now to prove its availability and long-term reliability in cruise shipping.

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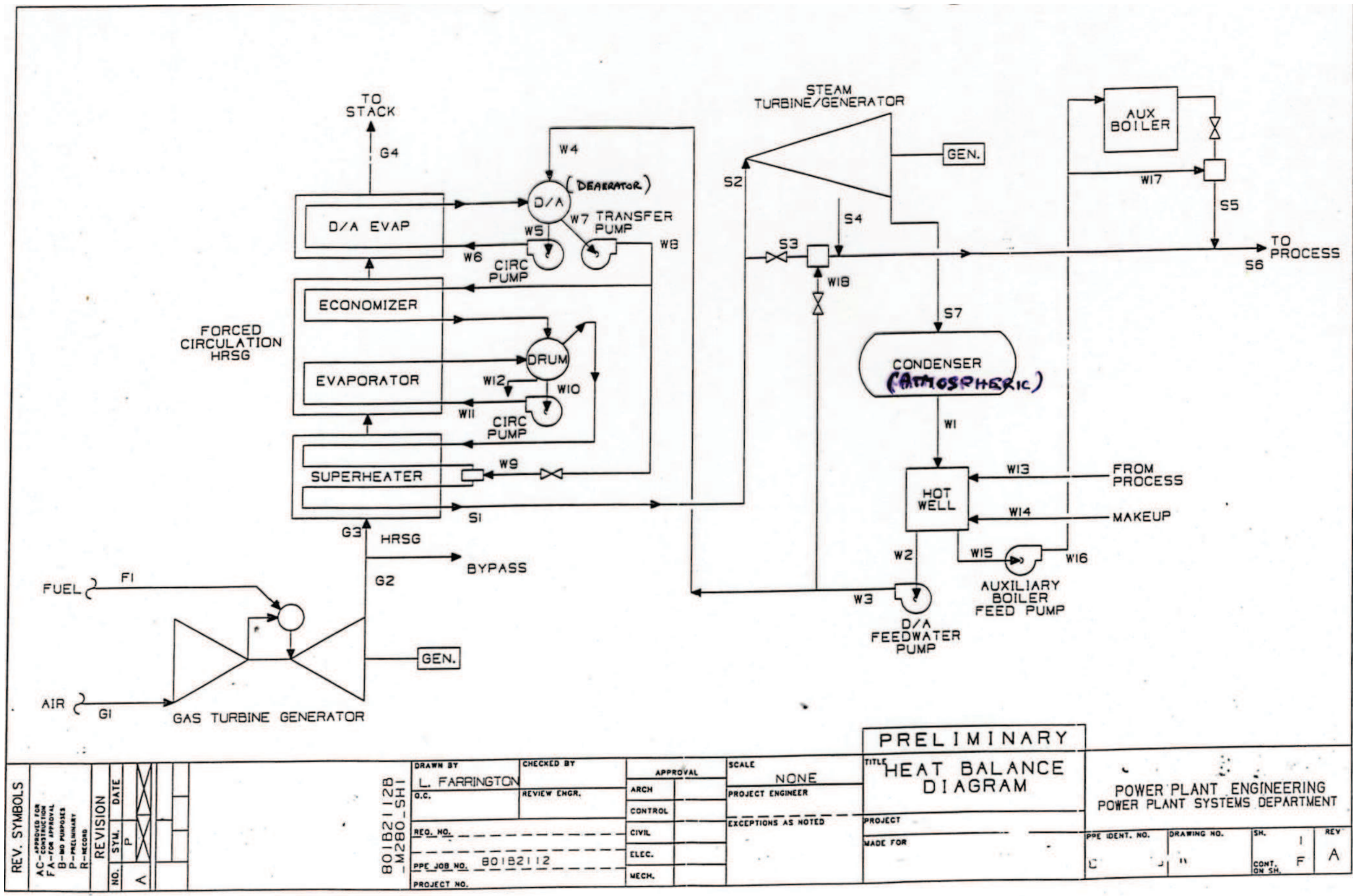

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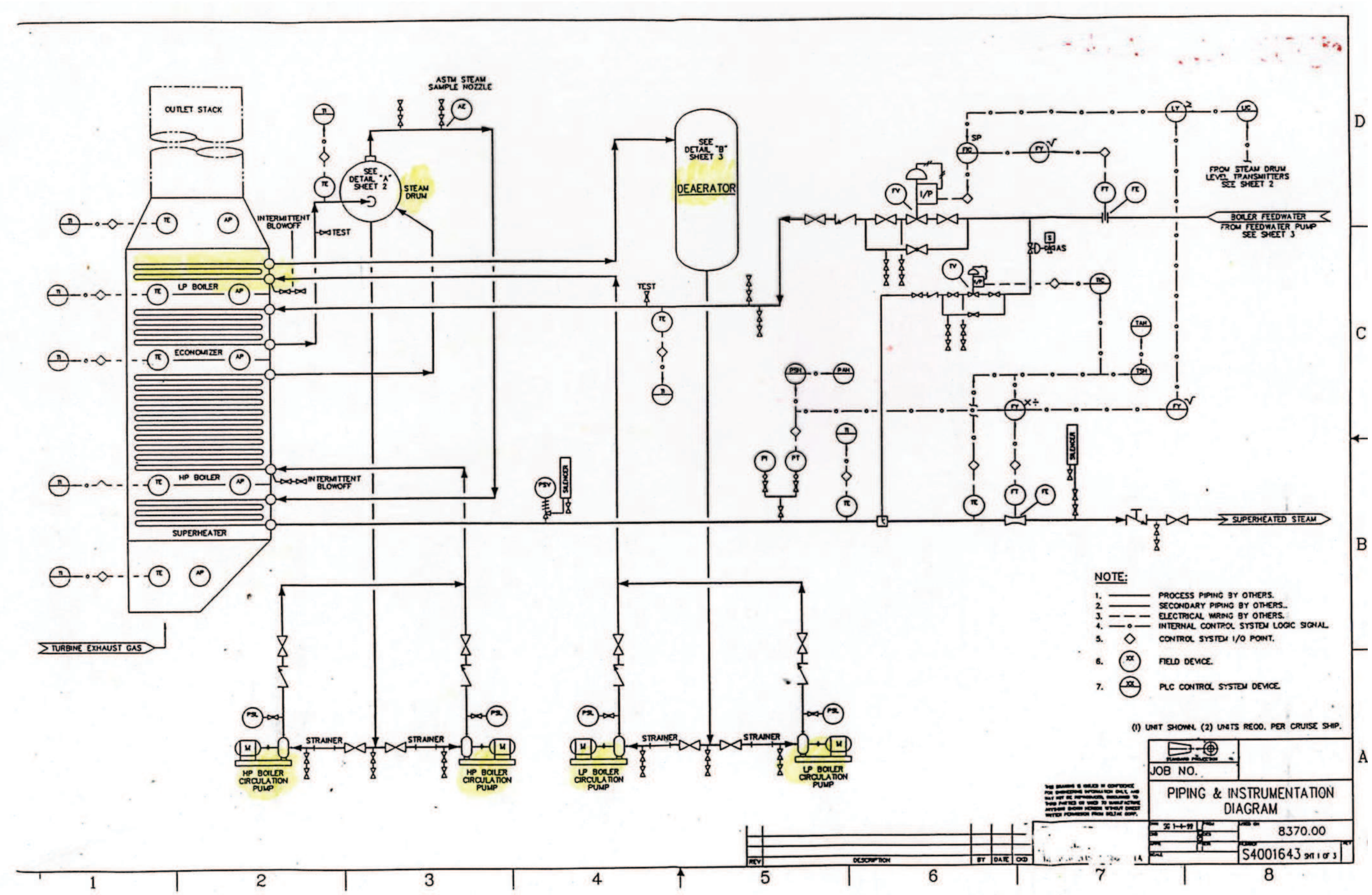

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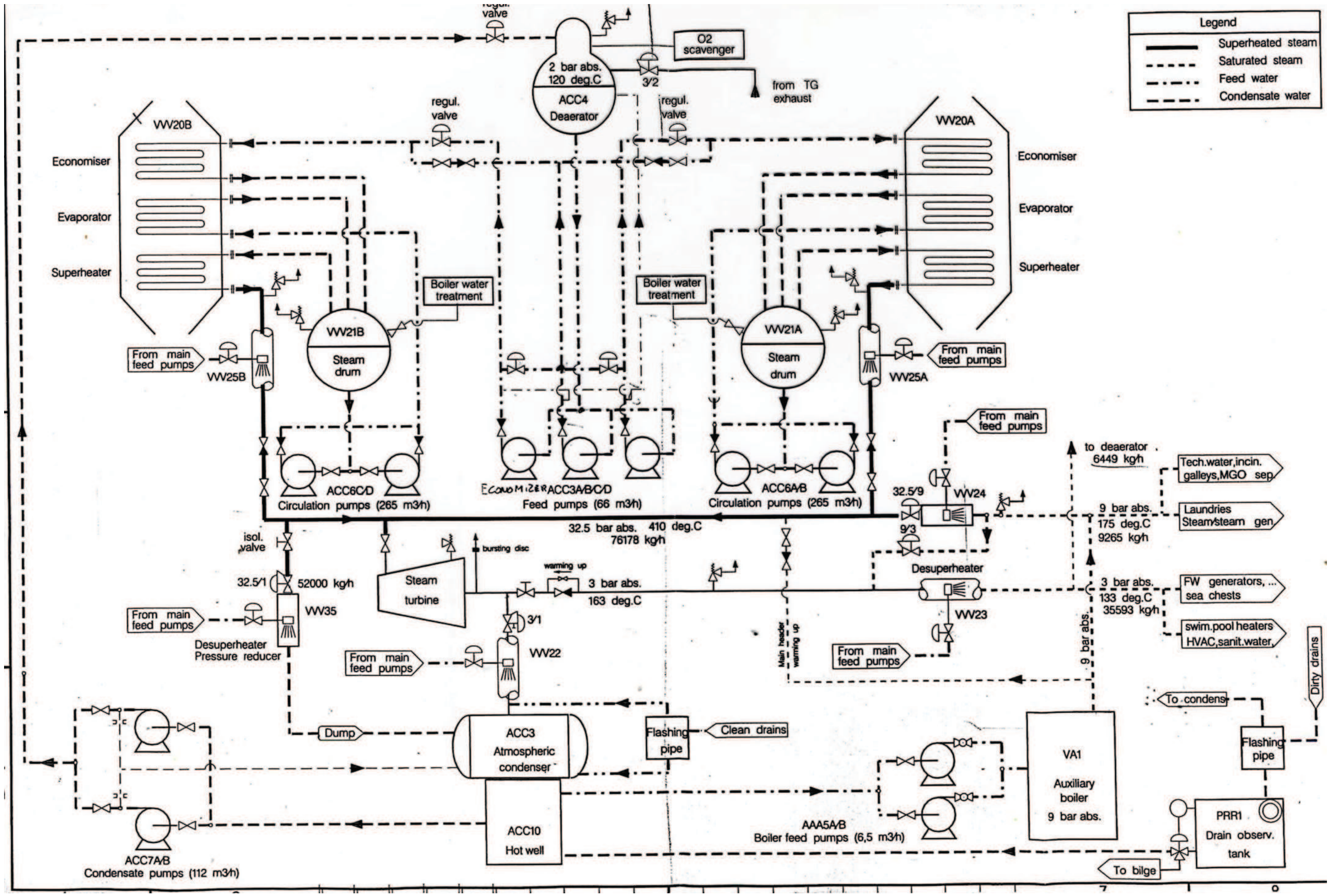

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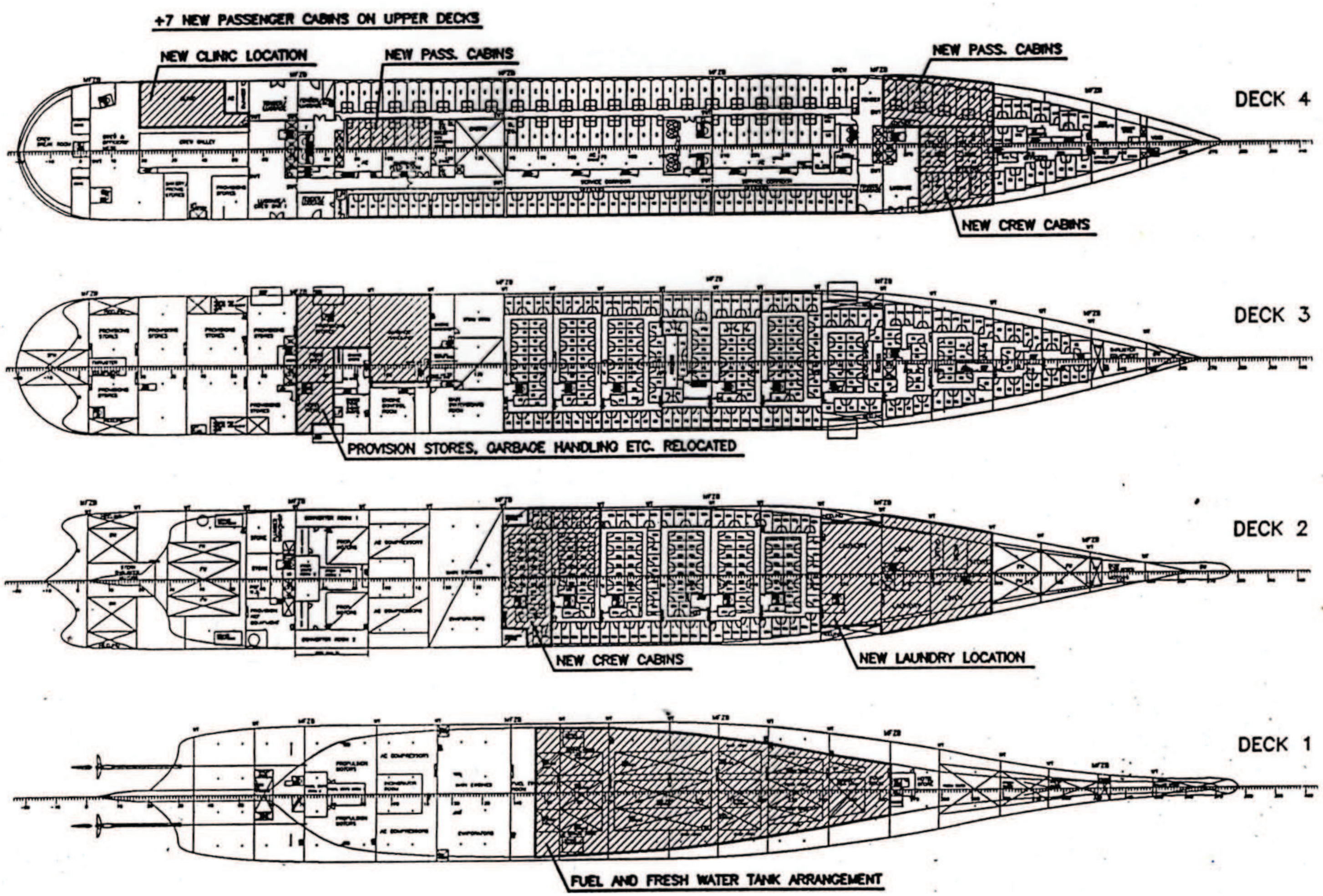

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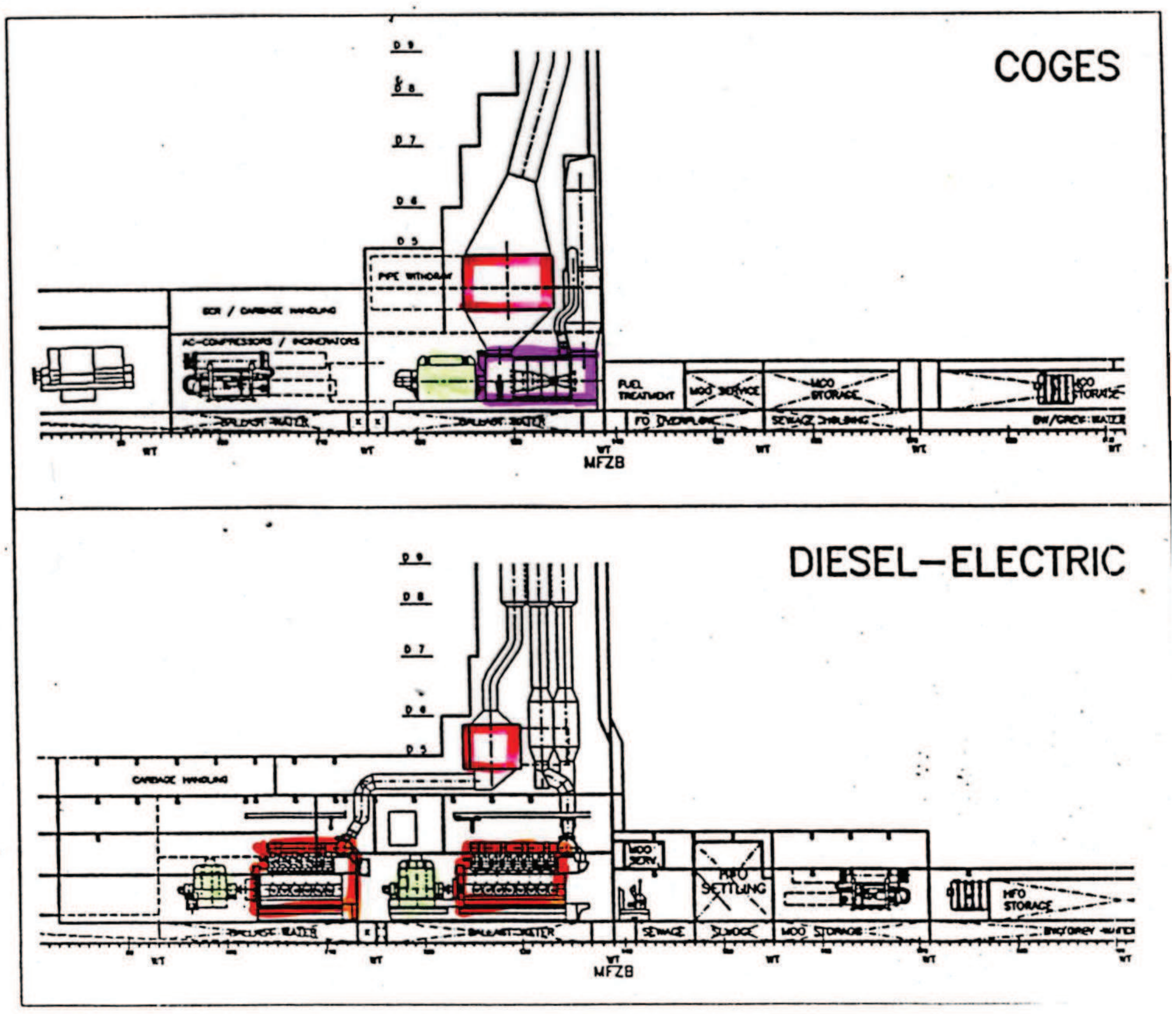

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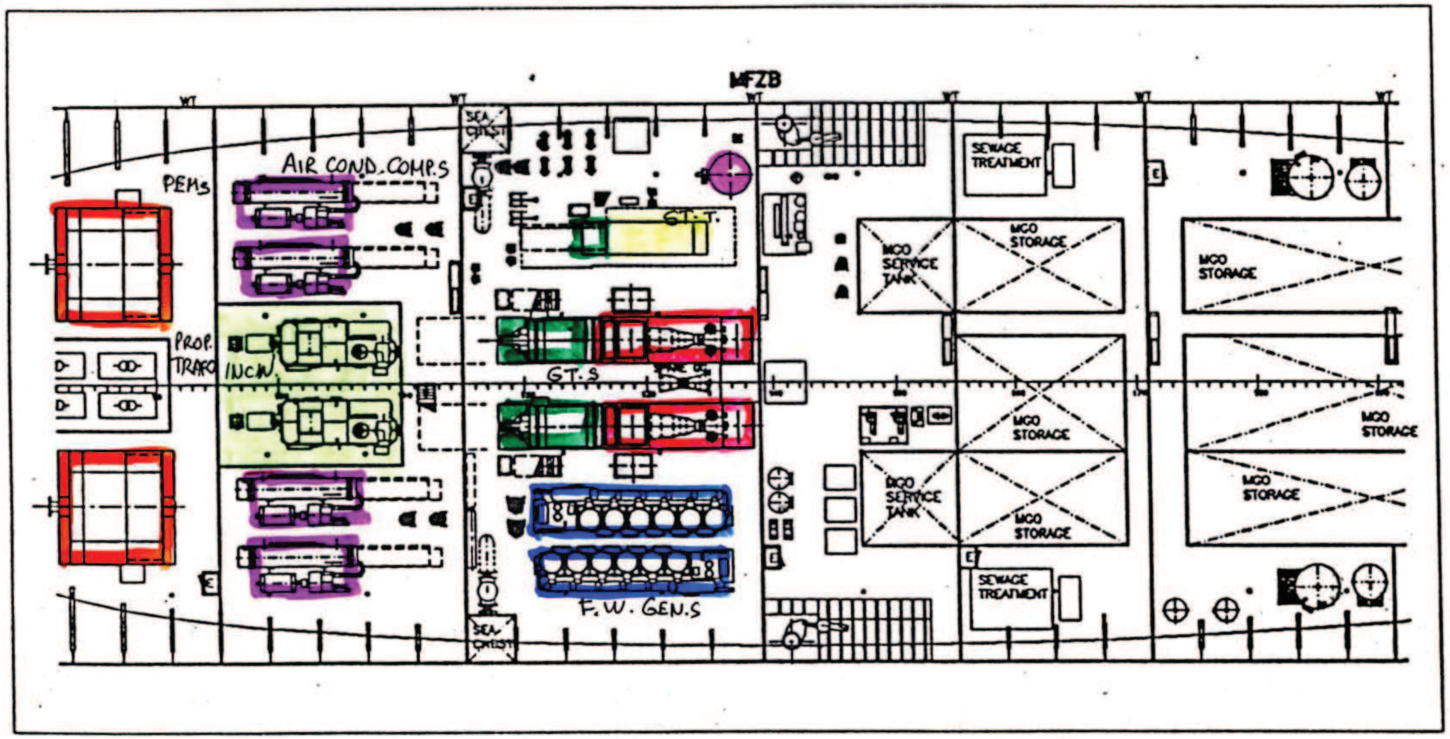

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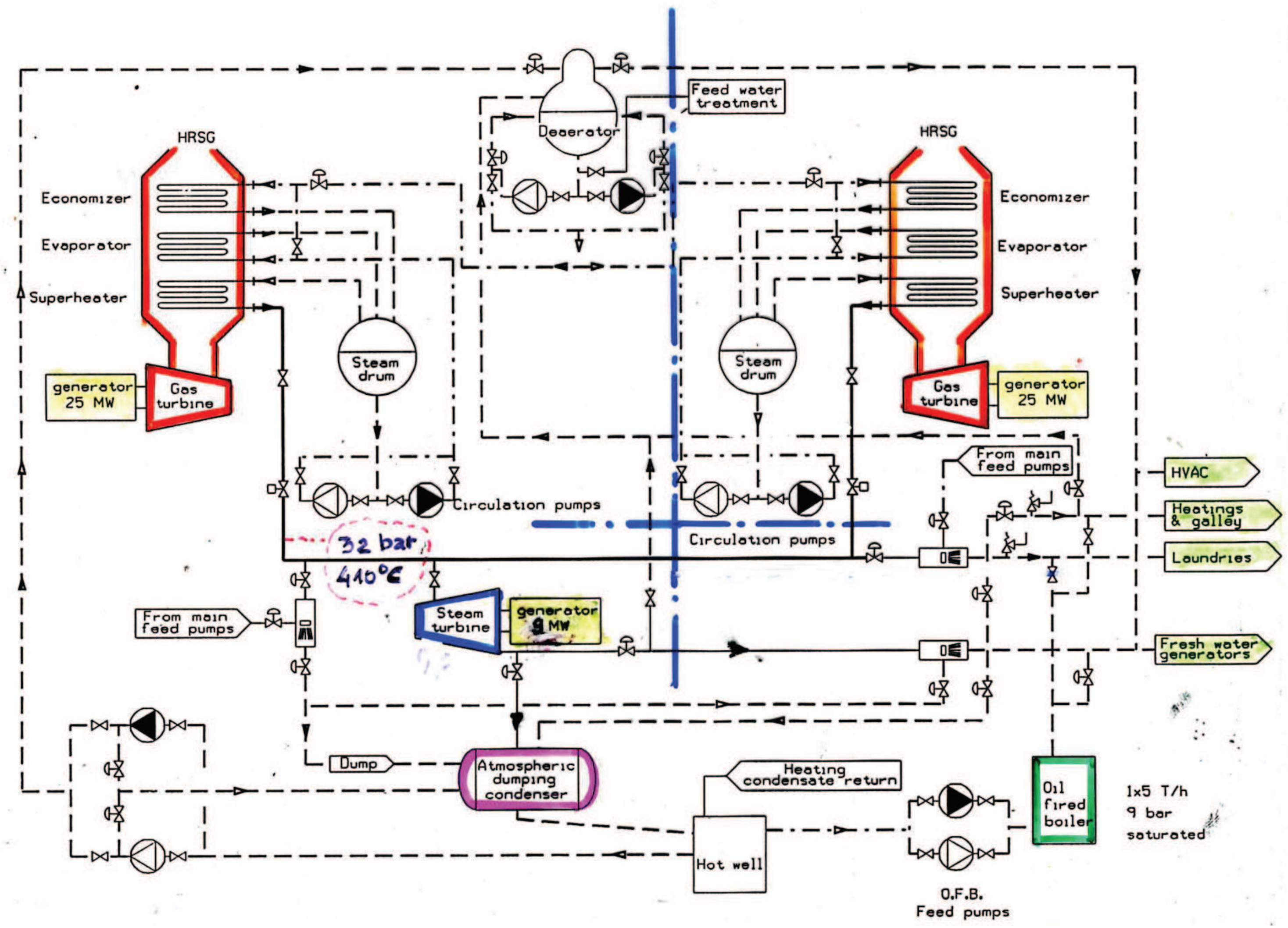

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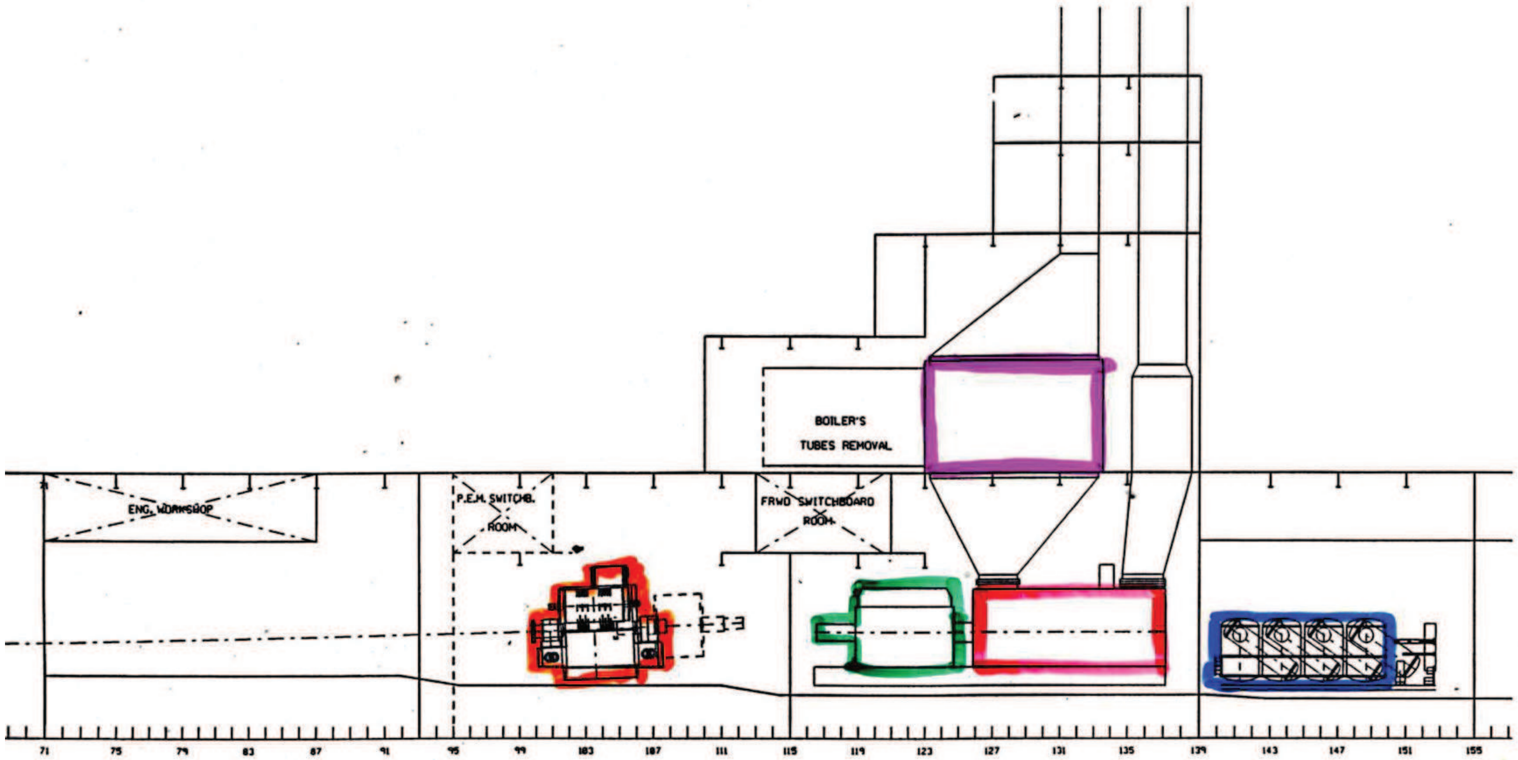

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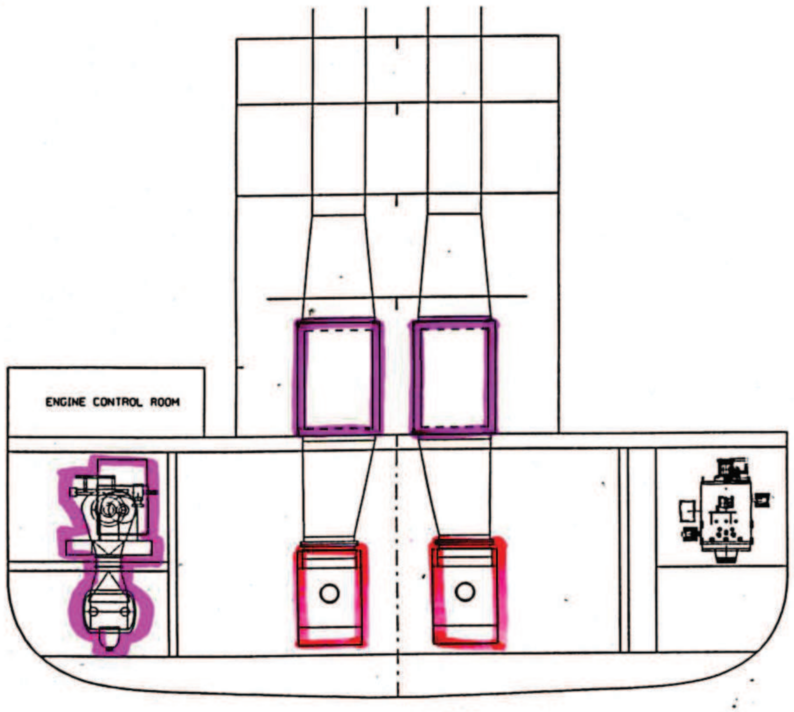
Impianti di propulsione navale



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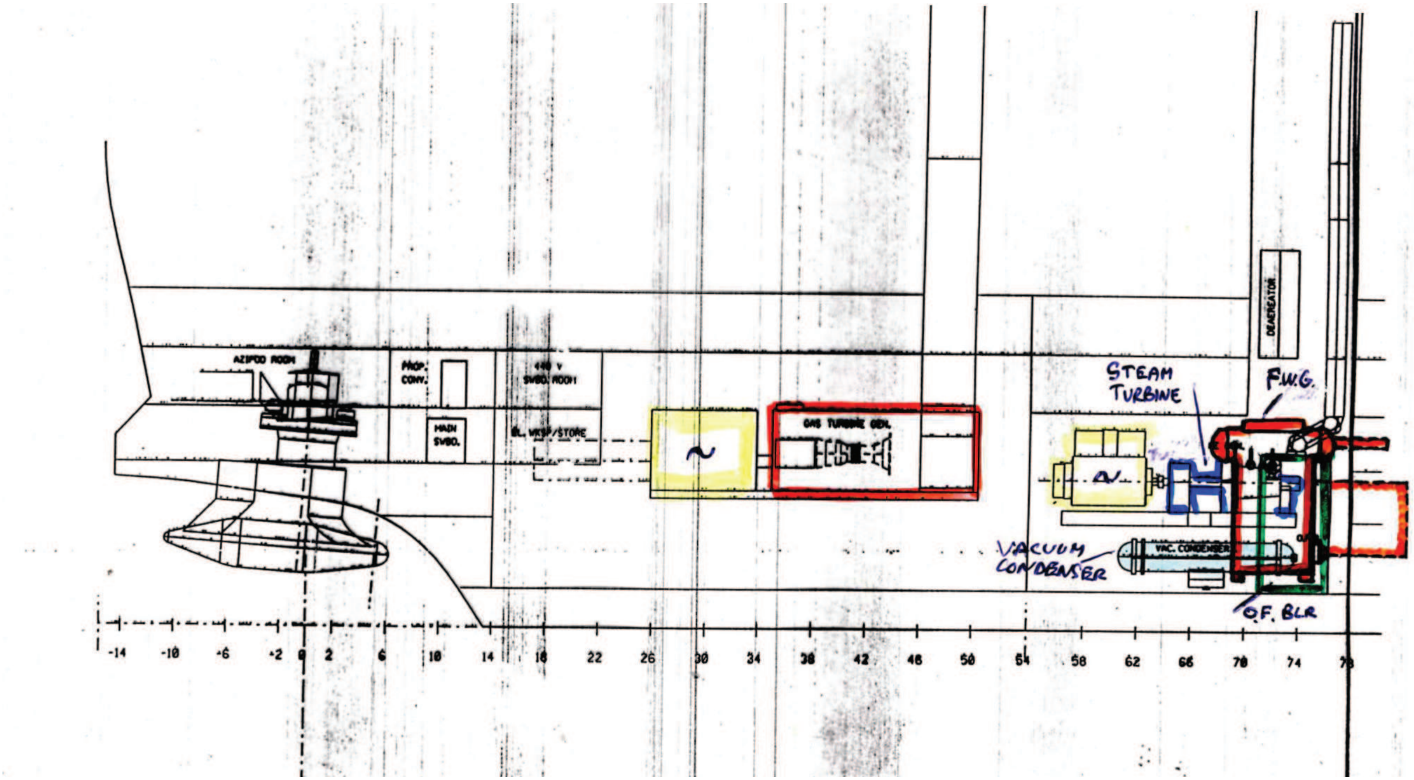

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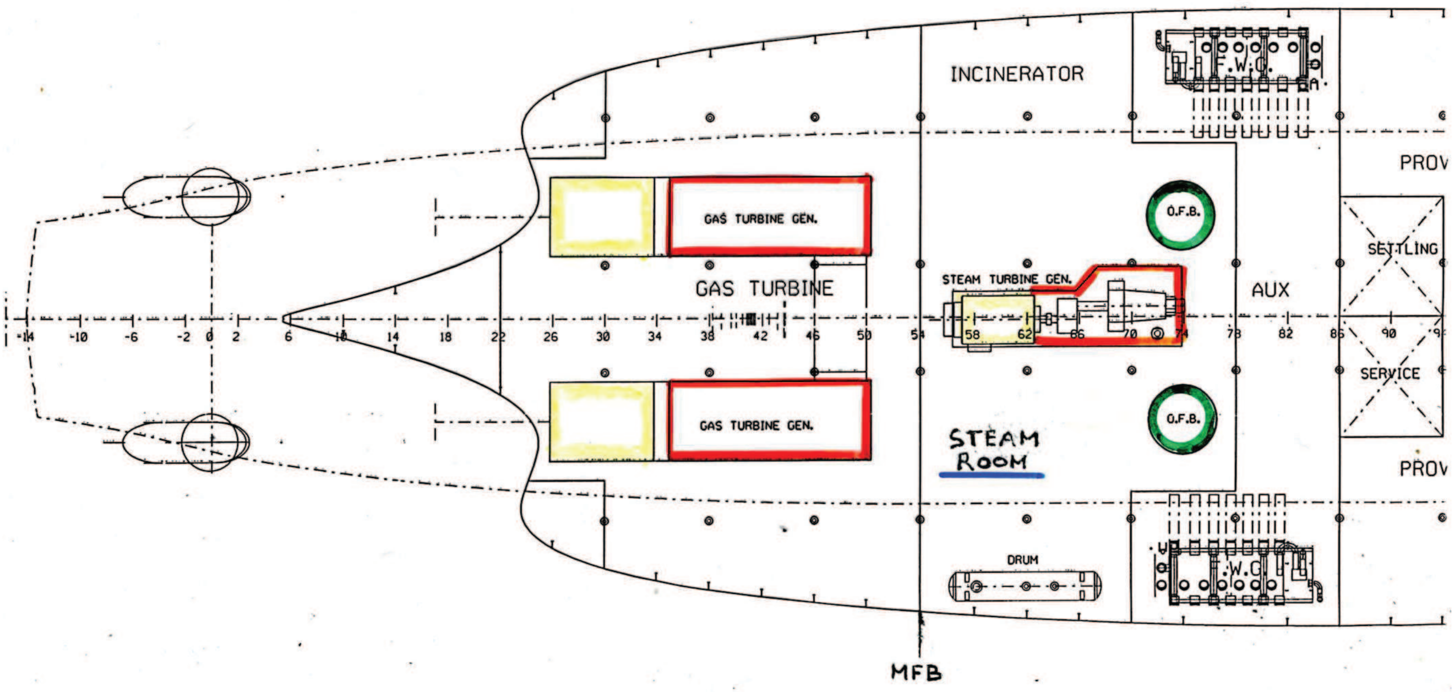

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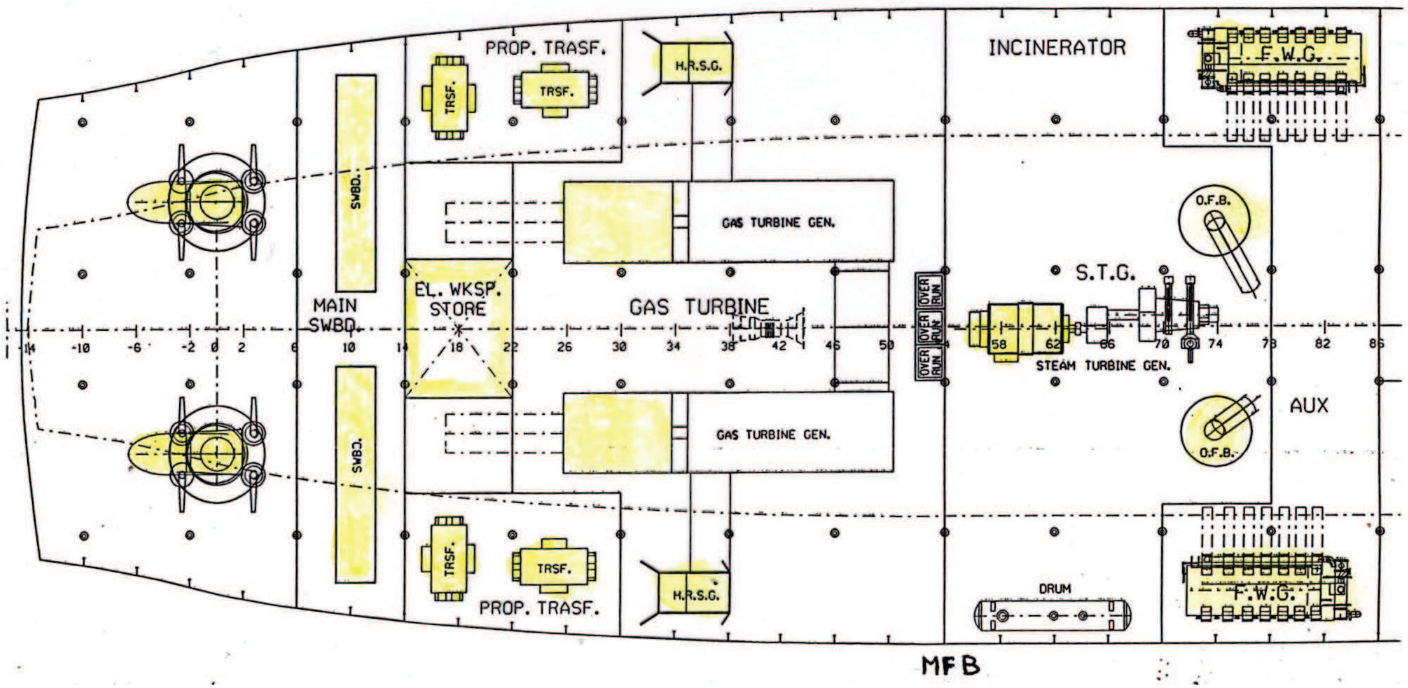

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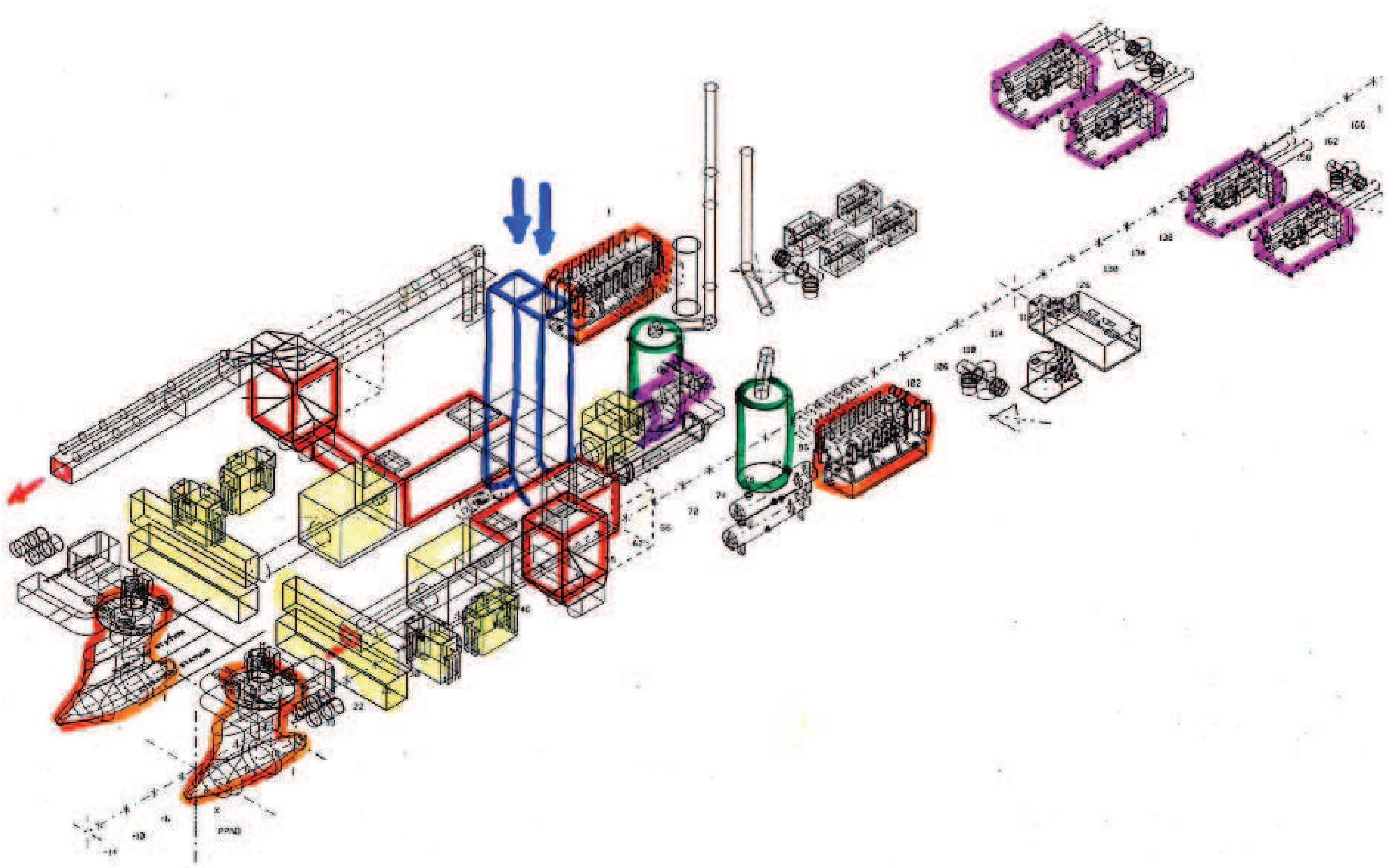

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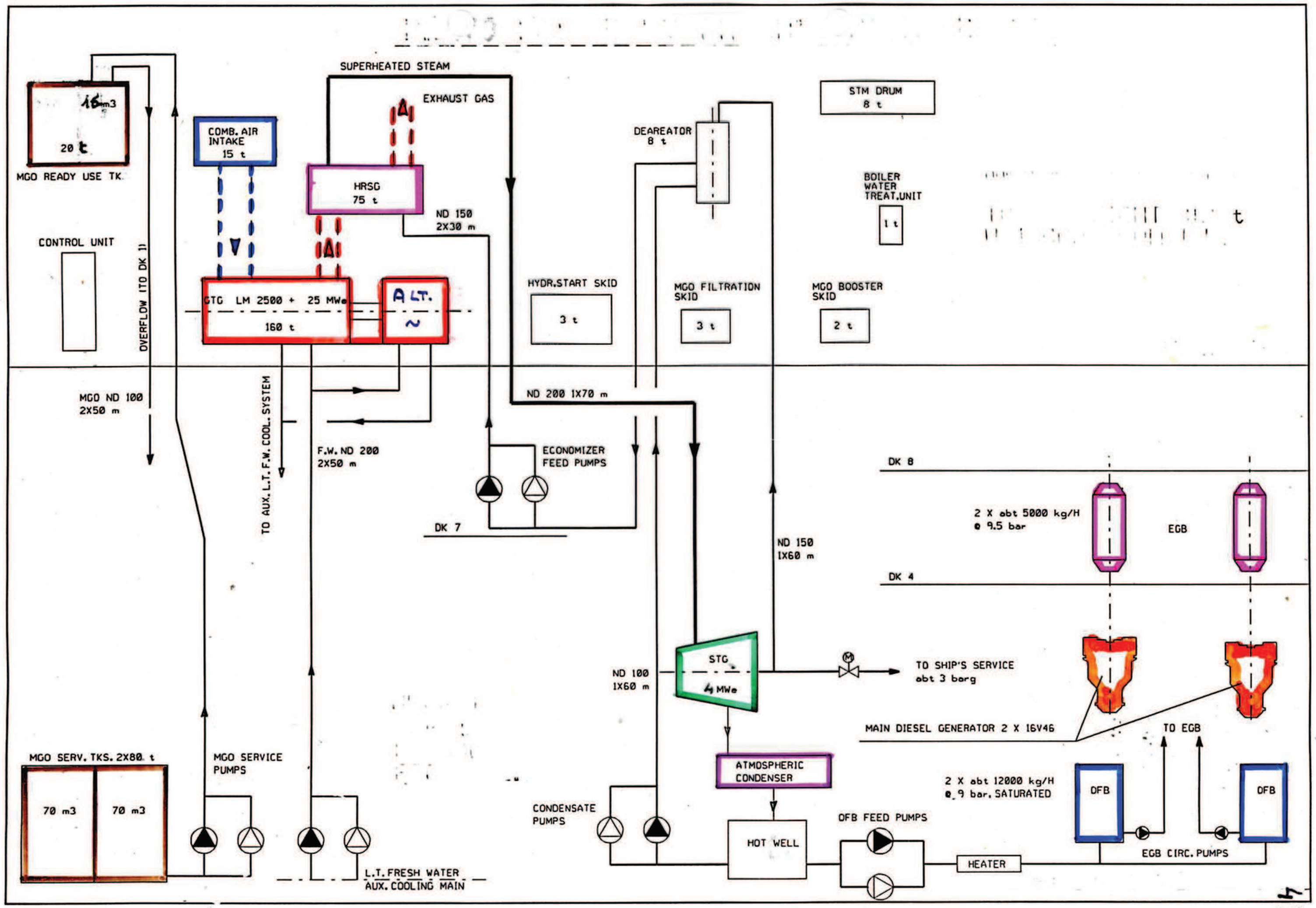

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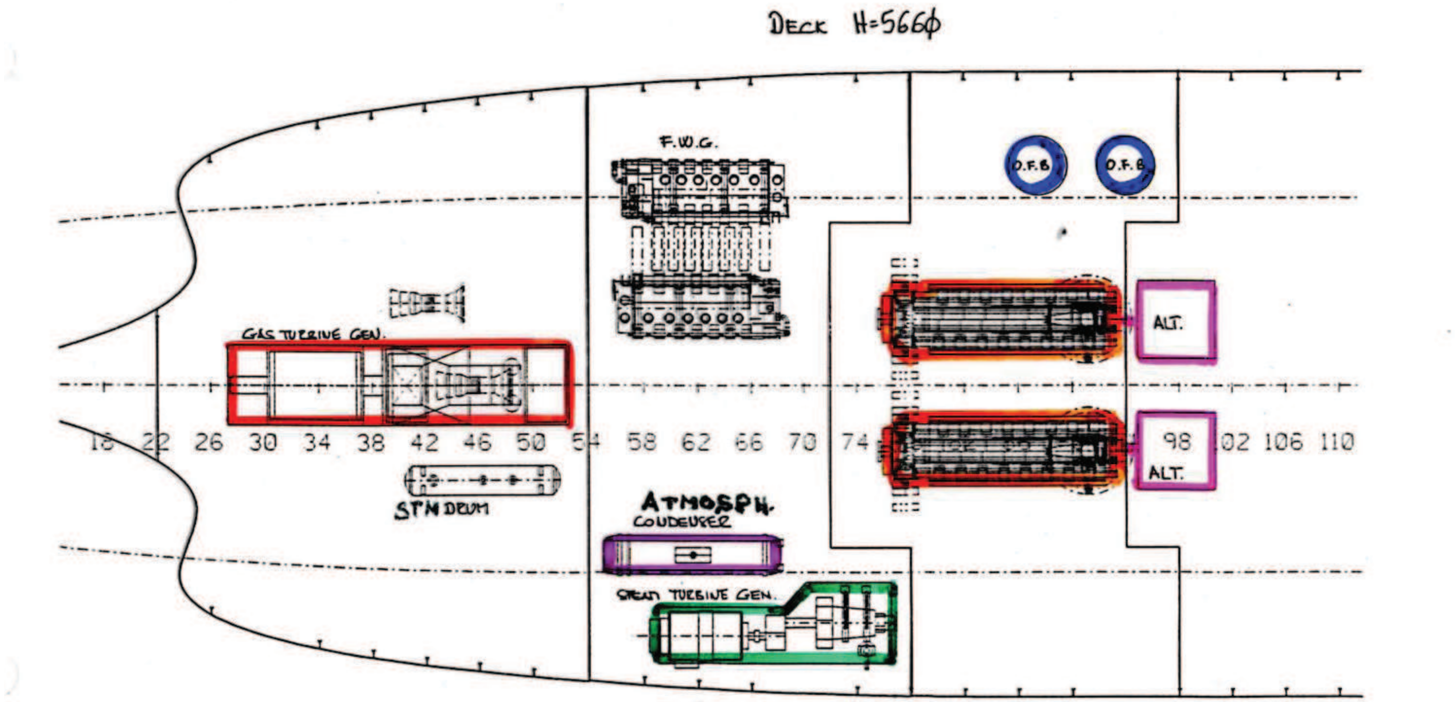

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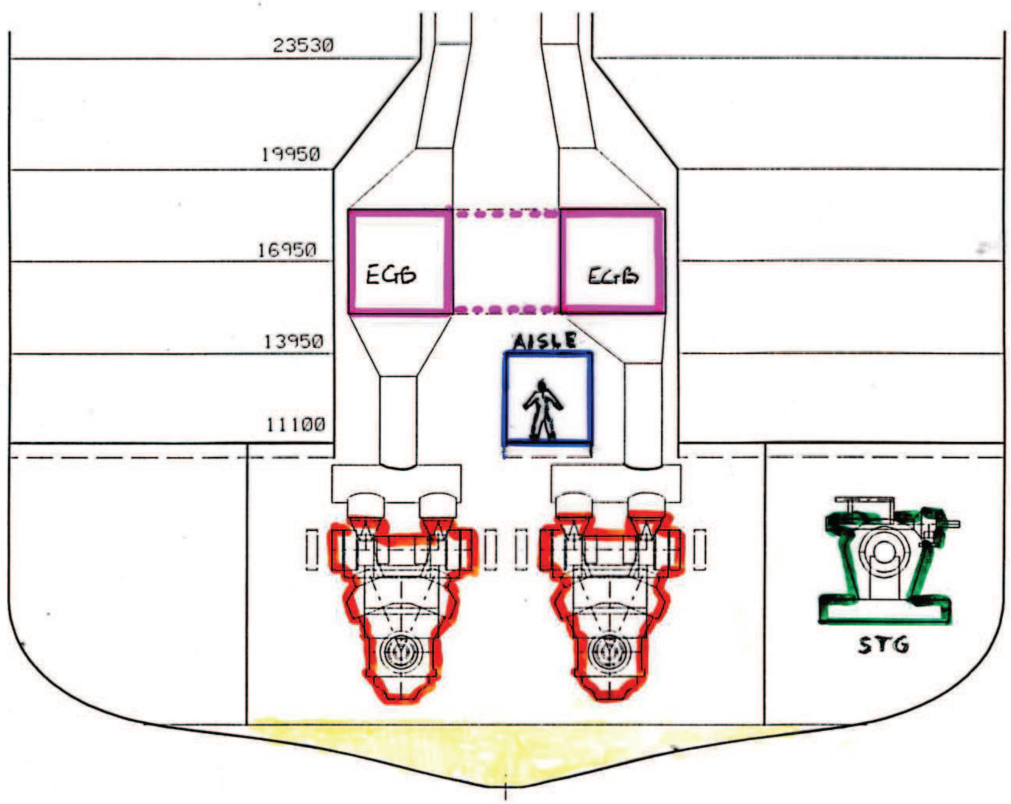

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