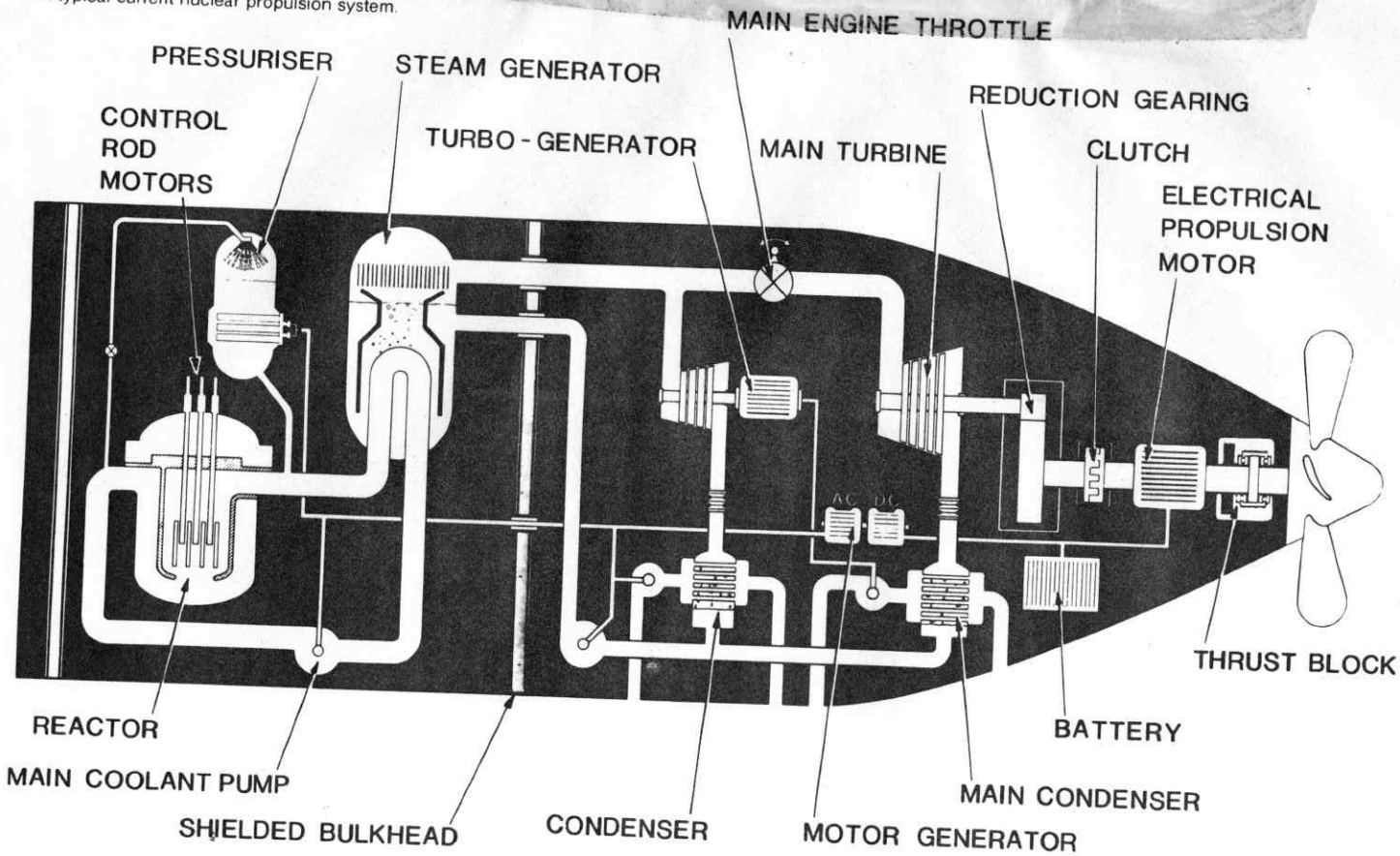
A typical current nuclear propulsion system.



The batteries in turn were always connected to motors driving the propeller shafts. This was a much heavier arrangement, but it was also much more flexible, and it made for higher surface speeds when charging. It was used by the US 'fleet type' submarine, and many postwar craft, in which underwater (motor) power actually exceeds surface (diesel) power.

Efficiency can be measured both in terms of energy loss in conversion (eg the thermal efficiency of a diesel) or in terms of weight or volume efficiency (engine weight per horsepower). To some extent the two can be traded off: a heavier but more energy-efficient engine can be paired with a smaller quantity of stored energy in the form of fuel oil. The latter is a much more efficient means of storing energy: a diesel achieves about 2 horsepower-hours (hph) per pound of oil

electrically to 5000°F. The induction coils heating the block would be protected from melting by helium cooling, and by being on the outside of the block. Thermal energy would be extracted directly by passing the working fluid of a Brayton-cycle (see below) engine through the carbon block. In theory, the hotter the block, the more efficient the entire cycle. Proper insulation would limit heat leakage, one study assuming a rate of 0.45 per cent per hour and a charging efficiency of 80 per cent. Net efficiency (electrical energy in/thermal energy out) was predicted to be 57.2 per cent, including heat leakage. No such system was ever tested in full-scale, but it may be relevant to note that, in the past, submarine steam engines (nothing like as hot) proved hazardous when their heat leaked into submerged submarines.

Kreislauf systems are better than batteries, but are still confined to brief bursts of power. That is, on a fuel basis a Kreislauf diesel is about three times as efficient as the relatively heavy lead-acid batteries. Hydrogen peroxide was better. The 1600-ton Type XVIII U-boat was to have had an underwater endurance of about ten hours at a full speed of about 24 knots. The new Thyssen TR 1700, the fastest diesel-electric submarine in the world, is credited with a *one-hour* sustained speed of 25 knots.

In theory, exotic fuels and oxidants can better these figures. When burned in air, hydrogen has about three times the energy per unit weight of conventional fuel oil, although it is much less dense. Metals such as beryllium and aluminium can contribute over twice the energy per unit weight of a fuel oil-

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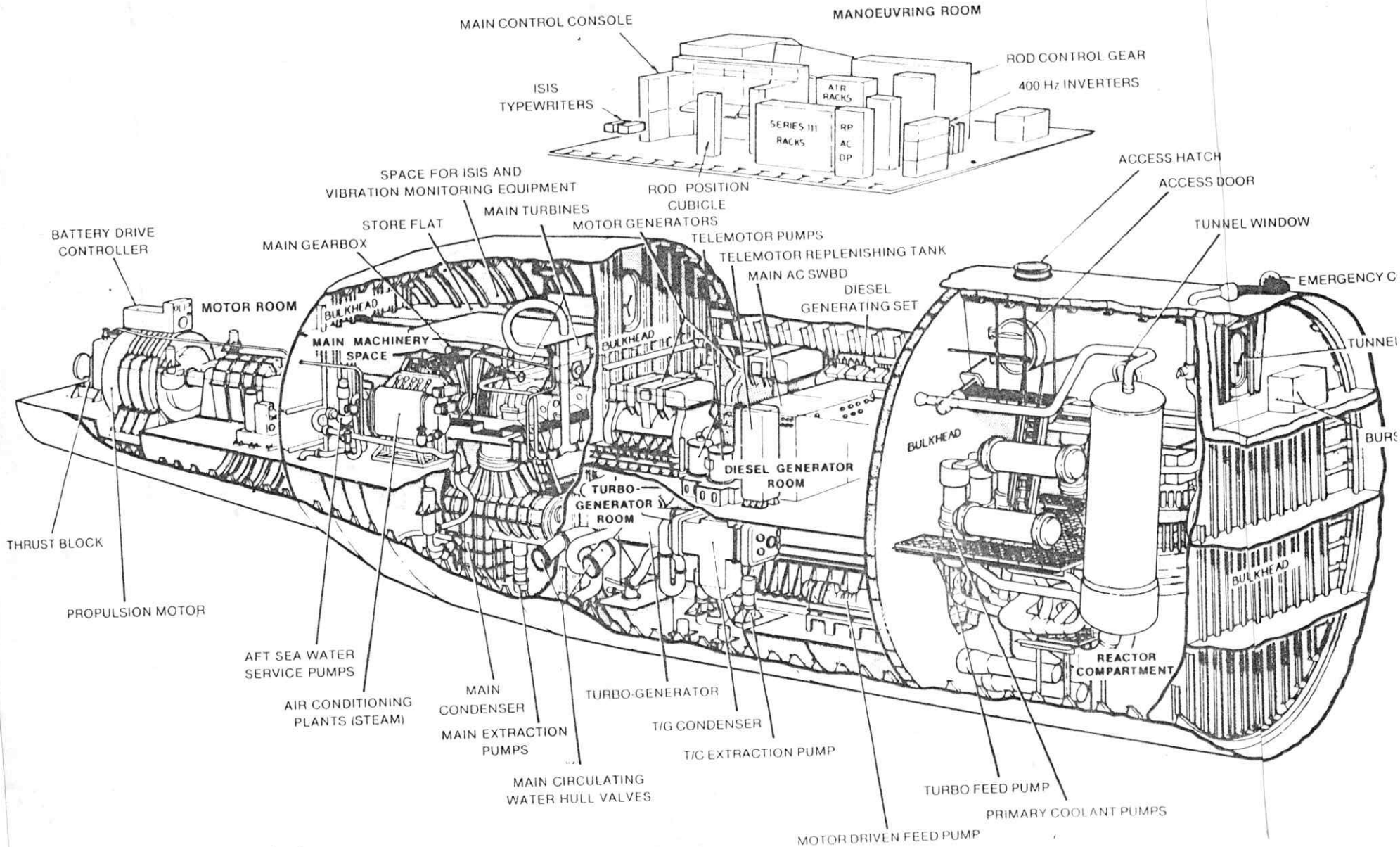

A British nuclear powerplant.