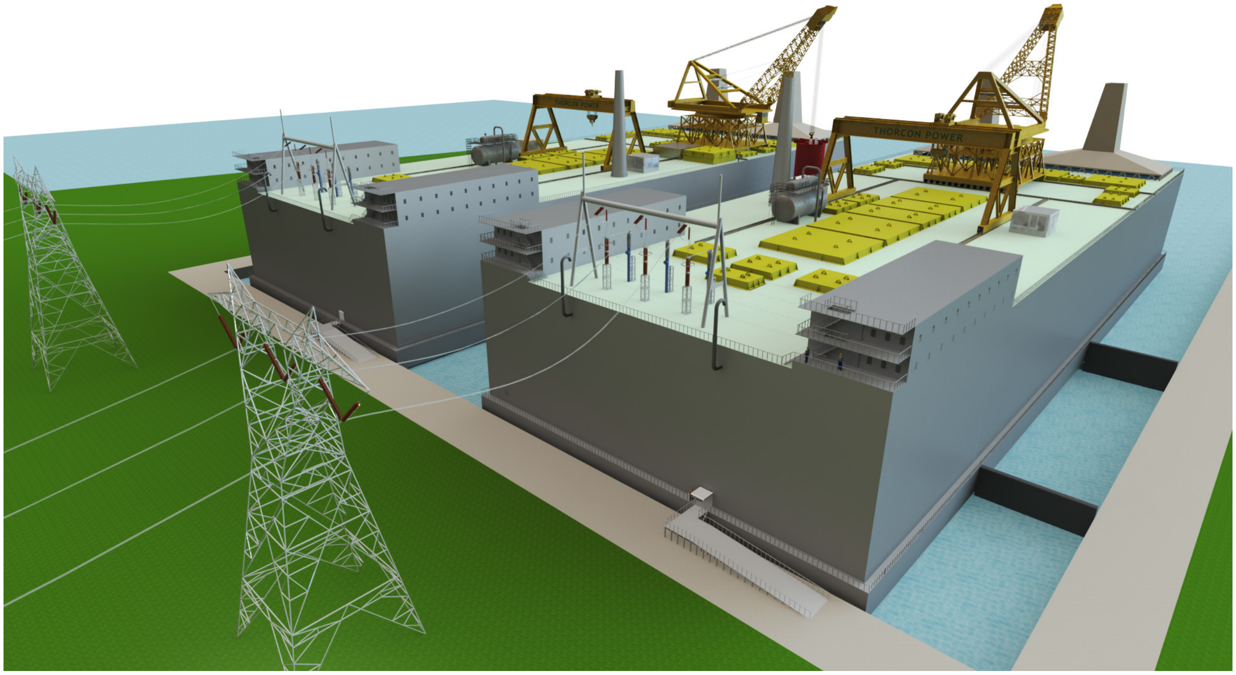

ThorConIsle

The ThorCon Team

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The Five Fundamental Features of ThorCon

ThorCon is Fixable Everything in the fission island except the structure itself is replaceable with little or no interruption in power output. Every four years the entire primary loop is changed out, returned to a centralized recycling facility, decontaminated, disassembled, inspected, and refurbished. Incipient problems are caught before they can turn into casualties. Major upgrades can be introduced without significantly disrupting power generation. Such renewable plants can operate indefinitely; but, if a ThorCon is decommissioned, the process is little more than pulling out but not replacing all the replaceable parts.

ThorCon is Walkaway Safe ThorCon is a molten salt reactor. Unlike all current reactors, the fuel is in liquid form. If the reactor overheats for whatever reason, ThorCon will shut itself down, and automatically handle the decay heat. This is built into the reactor physics. There is no need for any operator intervention. There is nothing the operators can do to prevent the shutdown and cooling.

ThorCon has at least three gas tight barriers between the fuelsalt and the atmosphere. The reactor operates at garden hose pressure. In the event of a primary loop rupture, there is no dispersal energy and no phase change. The spilled fuel merely flows to a drain tank where it is passively cooled. The most troublesome fission products, including ^{90}Sr and ^{137}Cs, are chemically bound to the salt. They will end up in the drain tank as well.

ThorCon is Ready to Go ThorCon requires no new technology. ThorCon is a straightforward scale-up of the successful Molten Salt Reactor Experiment (MSRE). There is no technical reason why a full-scale 250 MWe prototype cannot be operating within four years. The intention is to subject this prototype to all the failures and problems that the designers claim the plant can handle. As soon as the prototype passes these tests, commercial production can begin.

ThorCon is Rapidly Deployable The entire ThorCon plant including the building is manufactured in blocks on a shipyard-like assembly line. These 150 to 500 ton, fully outfitted, pre-tested blocks can be barged to the site, or assembled at the yard and towed to the site. A 1 GWe ThorCon will require less than 200 blocks. This produces order of magnitude improvements in productivity, quality control, and build time. A single large reactor yard can turn out twenty 1 GWe ThorCons per year. ThorCon is much more than a power plant; it is a system for building power plants.

ThorCon is Cheaper than Coal A ThorCon plant requires less of the planet's resources than a coal plant. Assuming efficient, evidence based regulation, ThorCon can produce clean, reliable, carbon free, electricity at less than the cost of coal.

Contents

1 ThorConIsle

1.1 Overview

ThorCon is a molten salt fission reactor. Unlike all current nuclear reactors, the fuel is in liquid form. It can be moved around with a pump, and passively drained in the event of a casualty.

ThorCon's reactor operates at about the same pressure as your garden hose. Standard nuclear reactors operate at over 130 bar (2000 psi). They require 9 inch thick pressure vessels and massive piping. The key forgings can only be done by a few specialized foundries. Worse, if there is a big piping failure, the pressurized water explodes into steam, which might spray radioactivity all over the place. This means the reactor, heat exchangers and pumps must be entombed in a massive, reinforced concrete mausoleum, where they are extremely difficult to repair or replace. Therefore, we pretend they will need little or no maintenance for the life of the plant. Reinforced concrete construction is horribly slow, nearly impossible to automate, difficult to inspect, and even more difficult to repair.

ThorCon uses normal piping thicknesses and easily automated, ship-style steel plate construction. In fact, ThorCons will be built in what is essentially a shipyard. There are two variants or *packages* of ThorCon:

ThorConLand A landside version in which 150 to 500 tons *blocks* are manufactured shipyard style, barged to the site, and erected.

ThorConIsle An offshore version in which an entire 500 MW plant is encapsulated in a hull, entirely built in a shipyard, towed to a nearshore or offshore site with a water depth of 0 to 10 m, ballasted down to the seabed, and if necessary surrounded by a breakwater.

Both packages use exactly the same fission island and turbine hall. The first ThorCons will use the Isle packaging. This packaging is the focus of this document.

Each ThorConIsle plant is based on one or more *hulls*, each containing two 250 MWe power modules, a 500 MW super-critical turbogenerator, gas insulated switchgear(GIS), a decay heat pond, and auxiliaries.

Figures 1 and 2 indicate the overall layout of a ThorCon hull. The *fission island* is at the forward end of the hull. Aft of the fission island is the *Steam Generating Cell*(SGC). Aft of the SGC is the *turbine hall*, which contains the turbogenerator, exciter, condensers, feedheaters, pumps, and condensate treatment. See Figures 4 and 5. The auxiliary boiler and sentry turbine are also located in the turbine hall. These components are used during start up — ThorCon has the capability of a black start — and the sentry turbine plays a role in certain upsets and grid failures.

The Gas Insulated Switchgear, which steps up the 25 kV generator voltage to grid voltage, is located in the *gishall* at the aft end of the Isle. Figures 6 and 7 indicate the electrical layout. The generator bus bars run aft to the low voltage Generator Circuit Breaker positioned on the hull centerline at the aft end of the turbine hall. The three single phase, water cooled transformers are located at the forward end of the gishall. The high voltage buses run aft to the High Voltage Circuit Breaker bays, and then up to the deck. If the Isle is sited close to shore as shown, the power will go ashore on conventional, air insulated transmission lines. Further offshore subsea cables will be used. If the site is more than 50 km offshore, then we will need to rectify the AC to DC. Space has been reserved in and above the gishall for the necessary Voltage Source Converters. Make up water and diesel oil tanks are located low in the Gishall. Two blackstart generators are positioned high in this space.

Figures 6 and 8 show the massive seawater pumps located outboard of the condensers. The superstructure on either side of the gishall contains support systems, the control room, and accommodations.

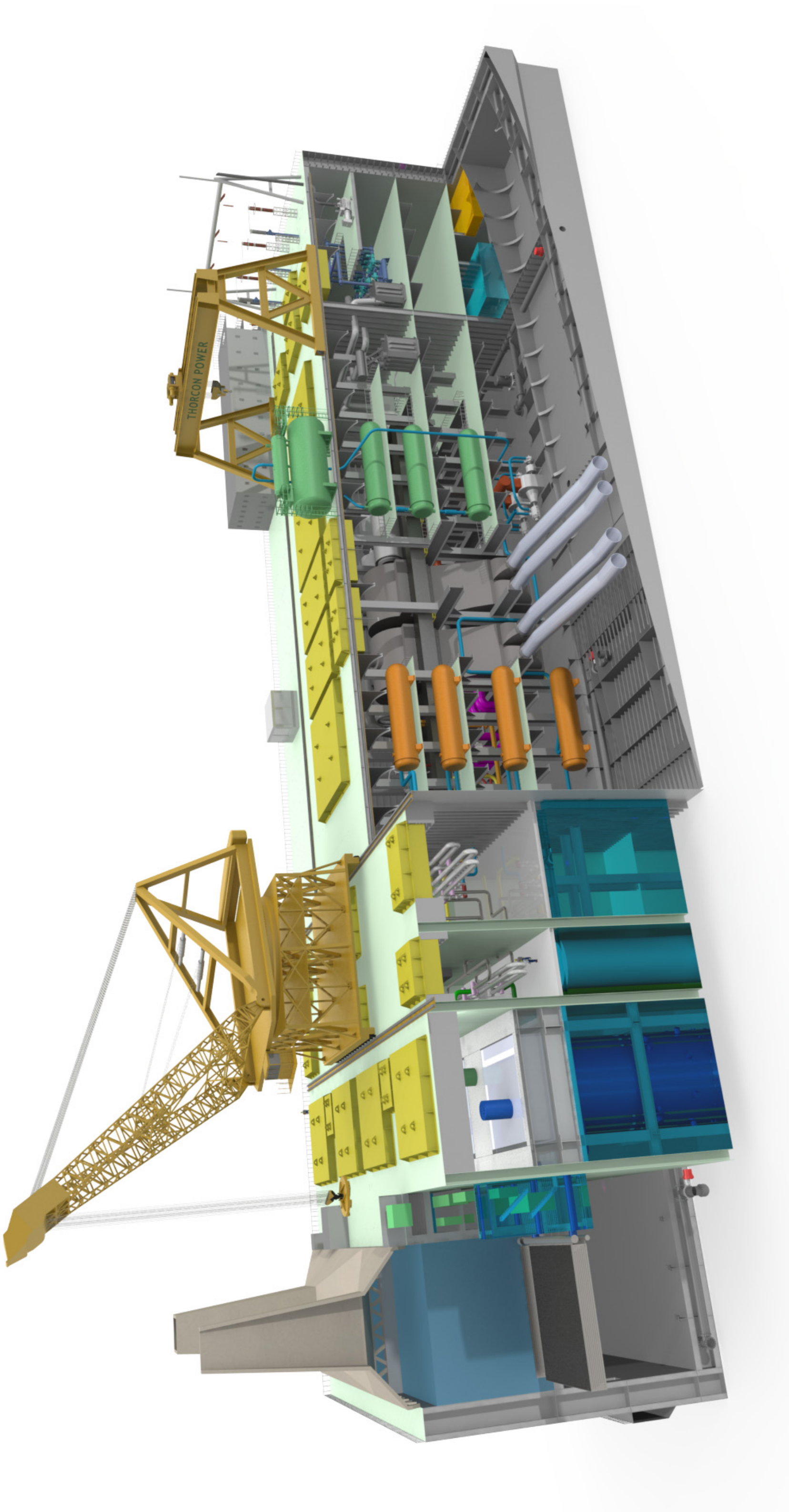


Figure 1: ThorConIsle Cutaway View

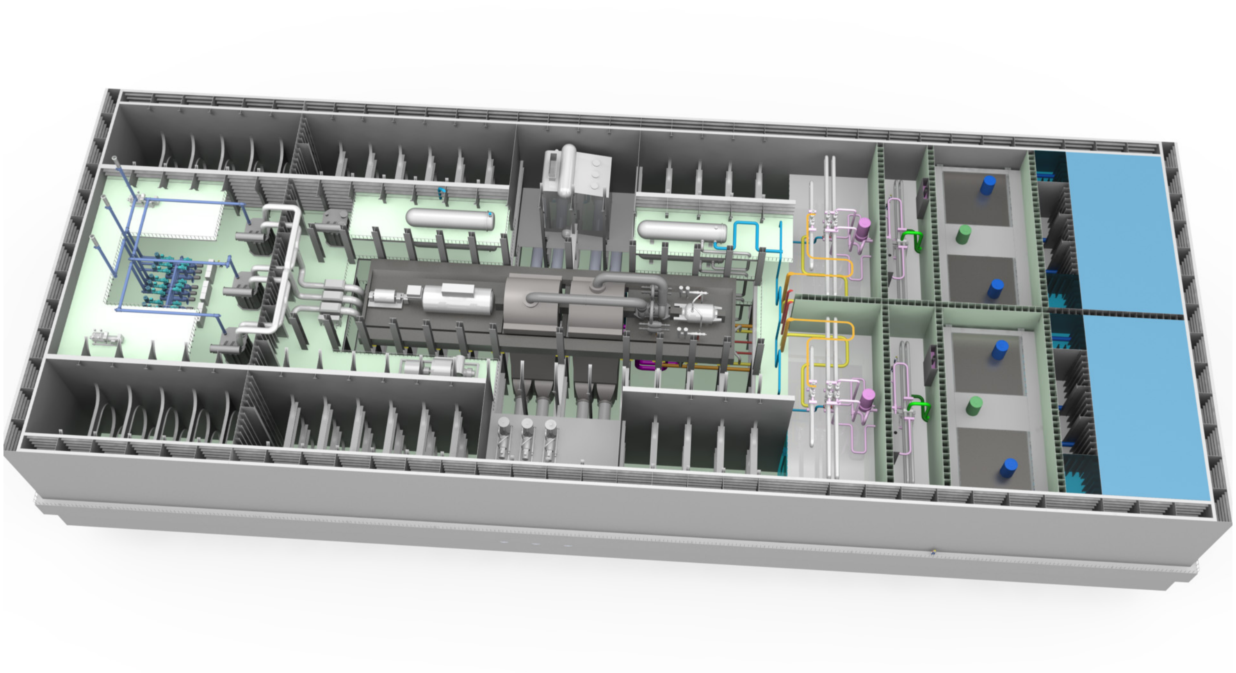


Figure 2: ThorConIsle Plan View

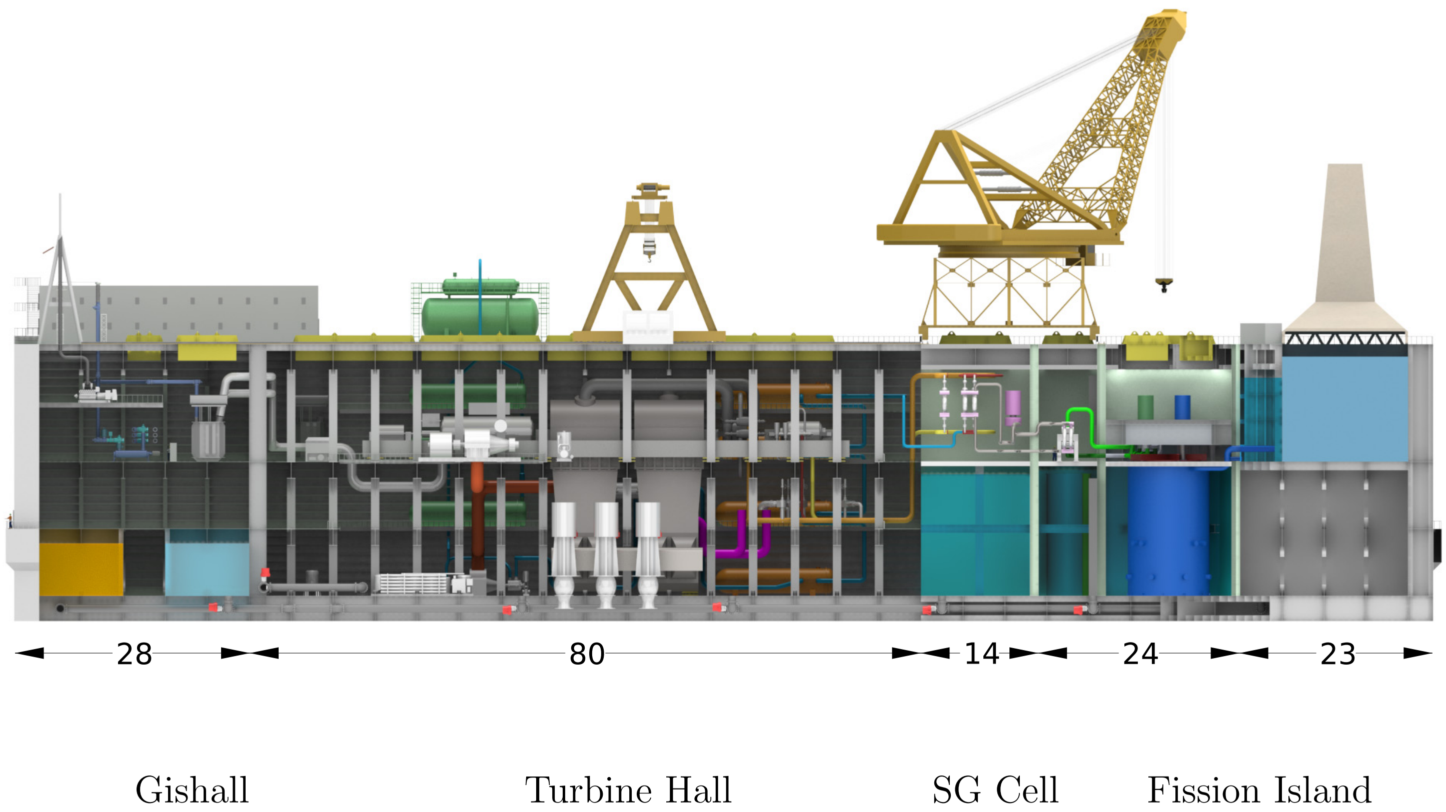


Figure 3: ThorConIsle Profile looking Port. Fission island is 1/4 of the total length.

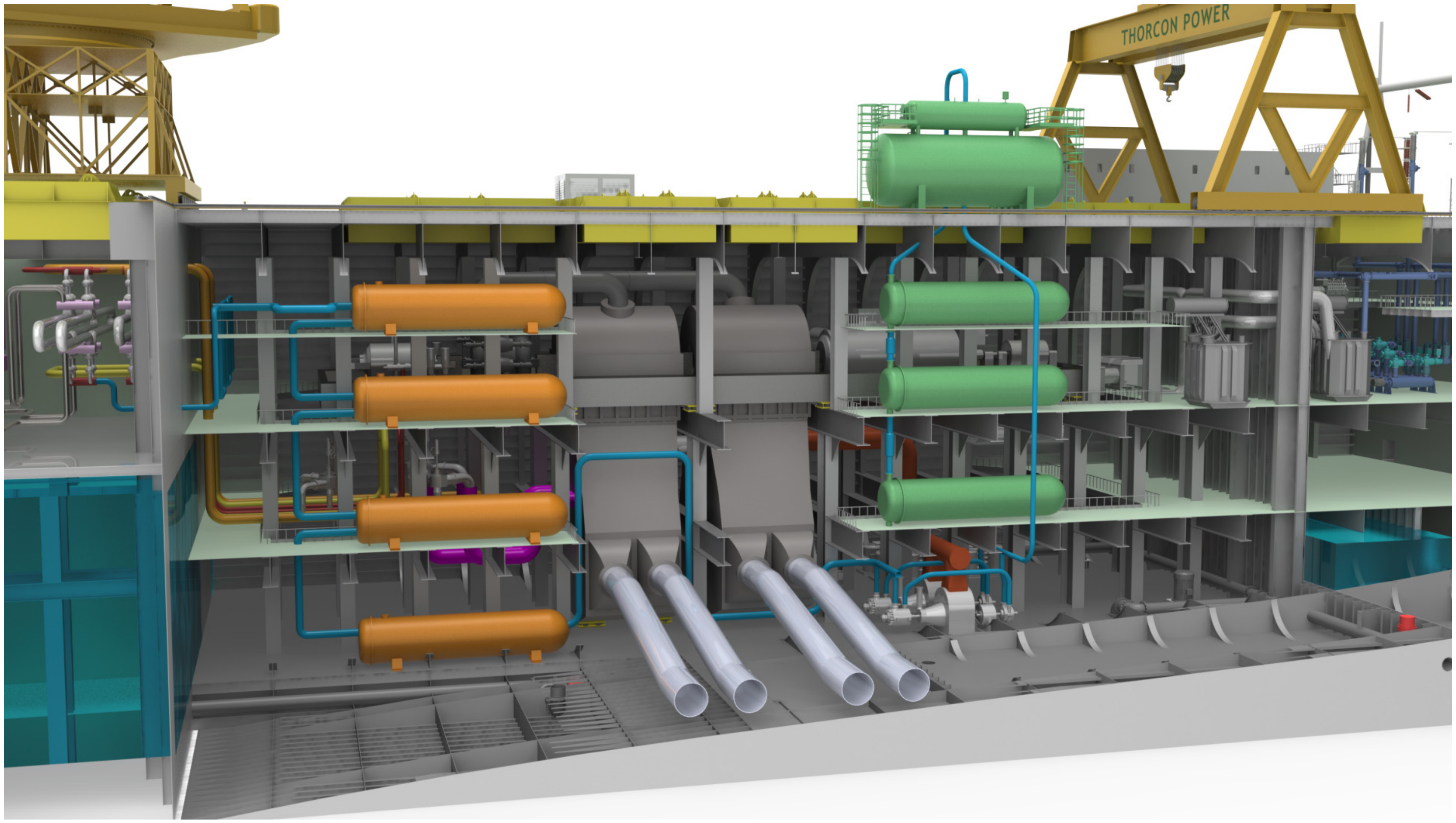


Figure 4: Turbine Hall looking starboard. HP Feedheaters shown in orange; LP in green.

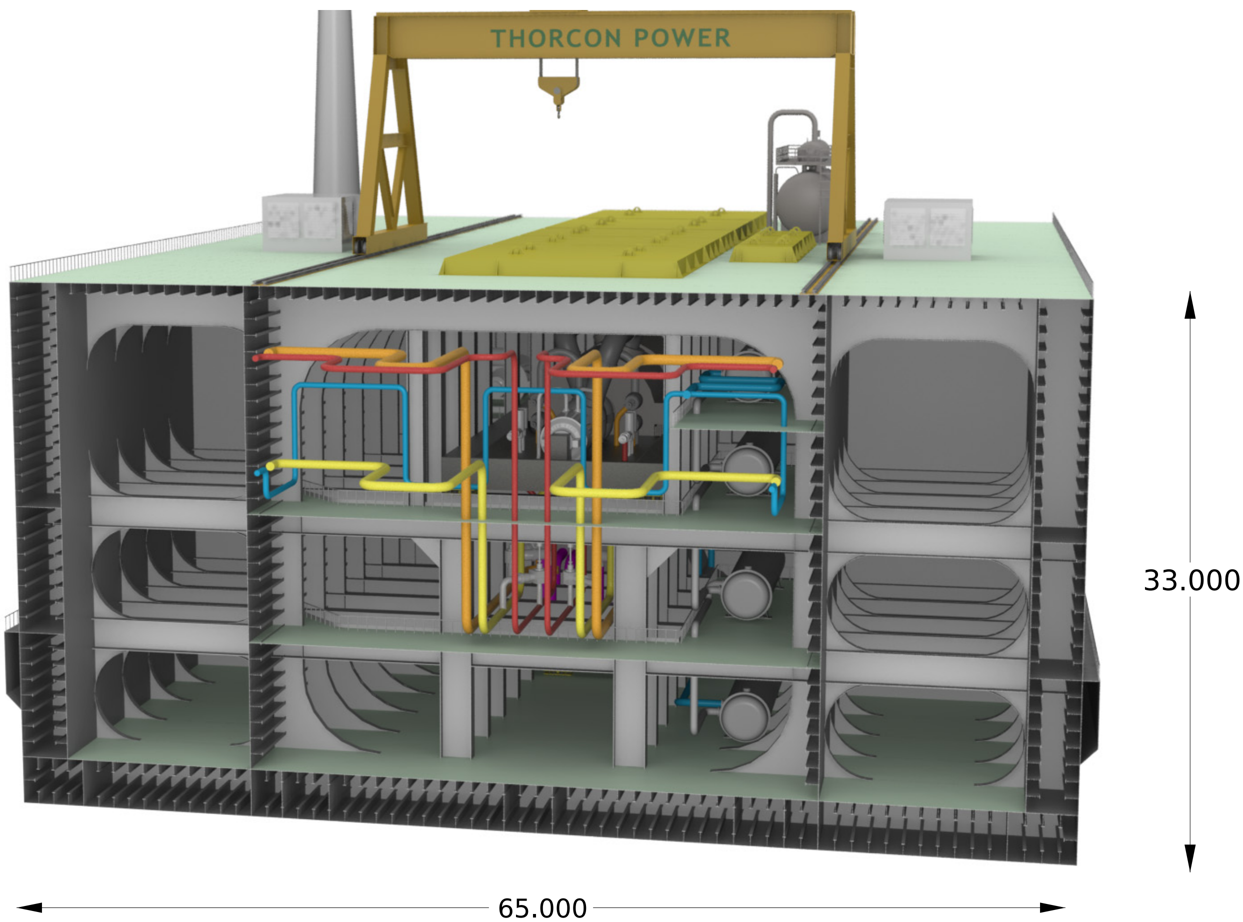


Figure 5: Turbine Hall looking aft.

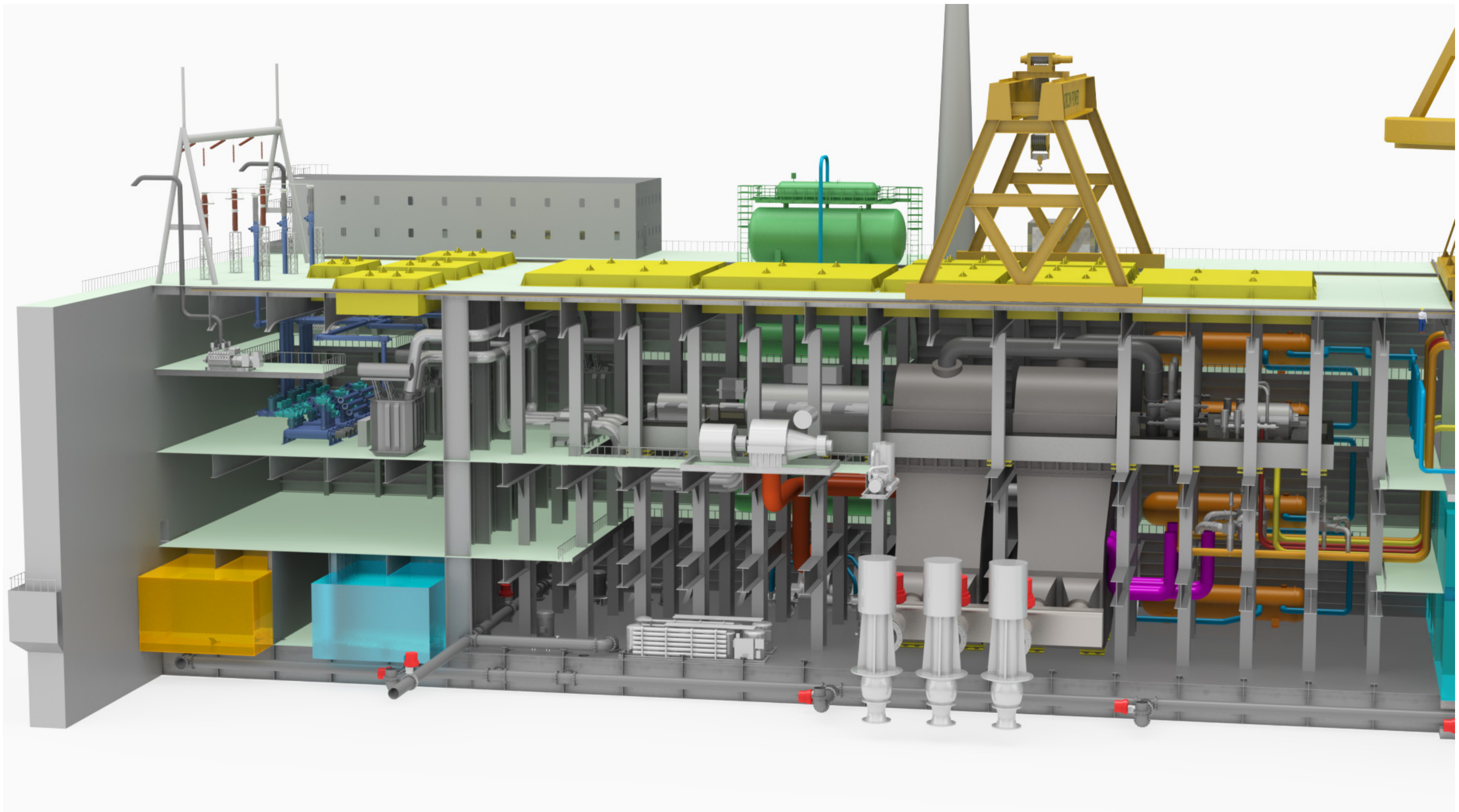


Figure 6: Gishall and Turbine Hall looking port.

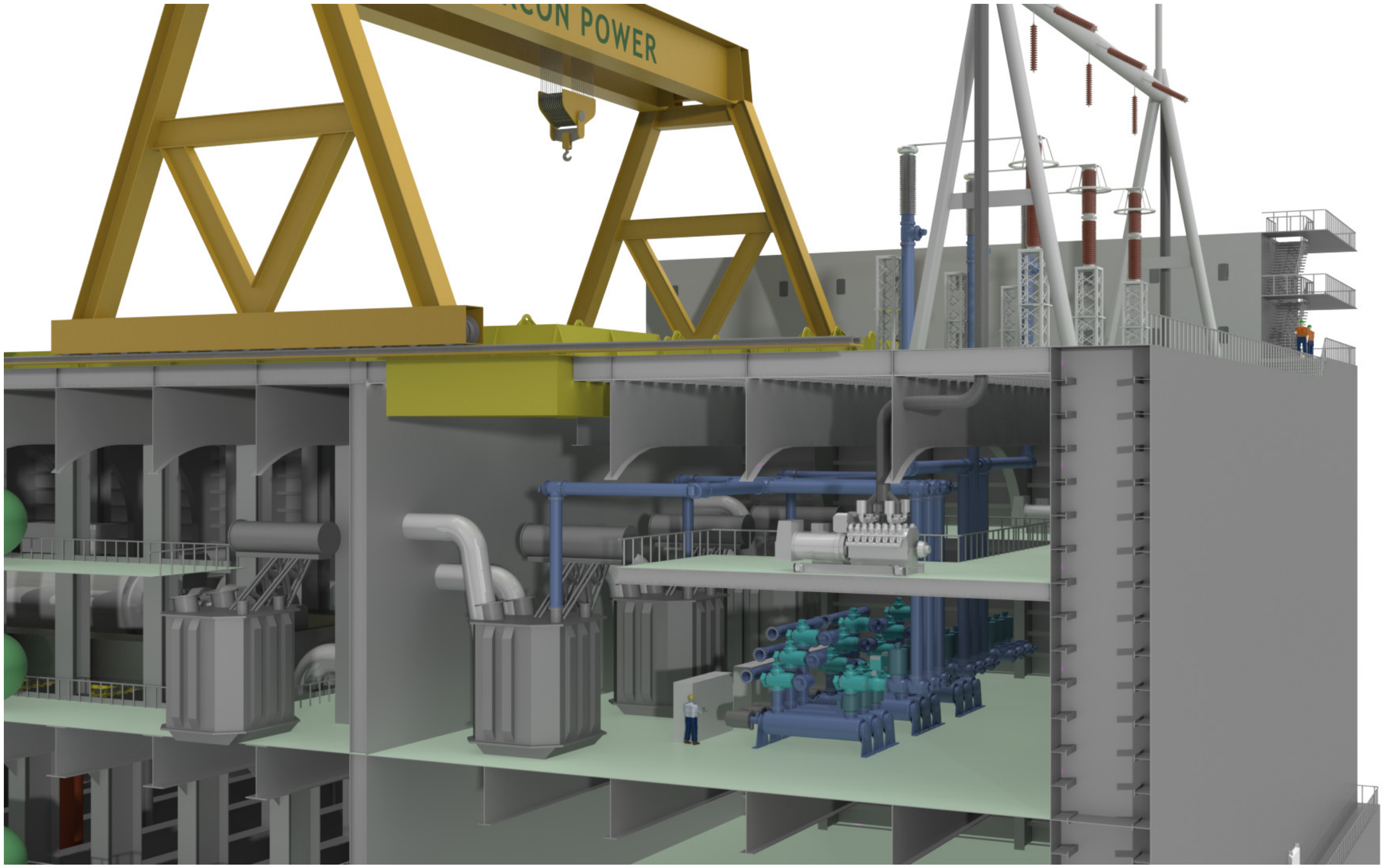


Figure 7: Near shore Gishall Arrangement

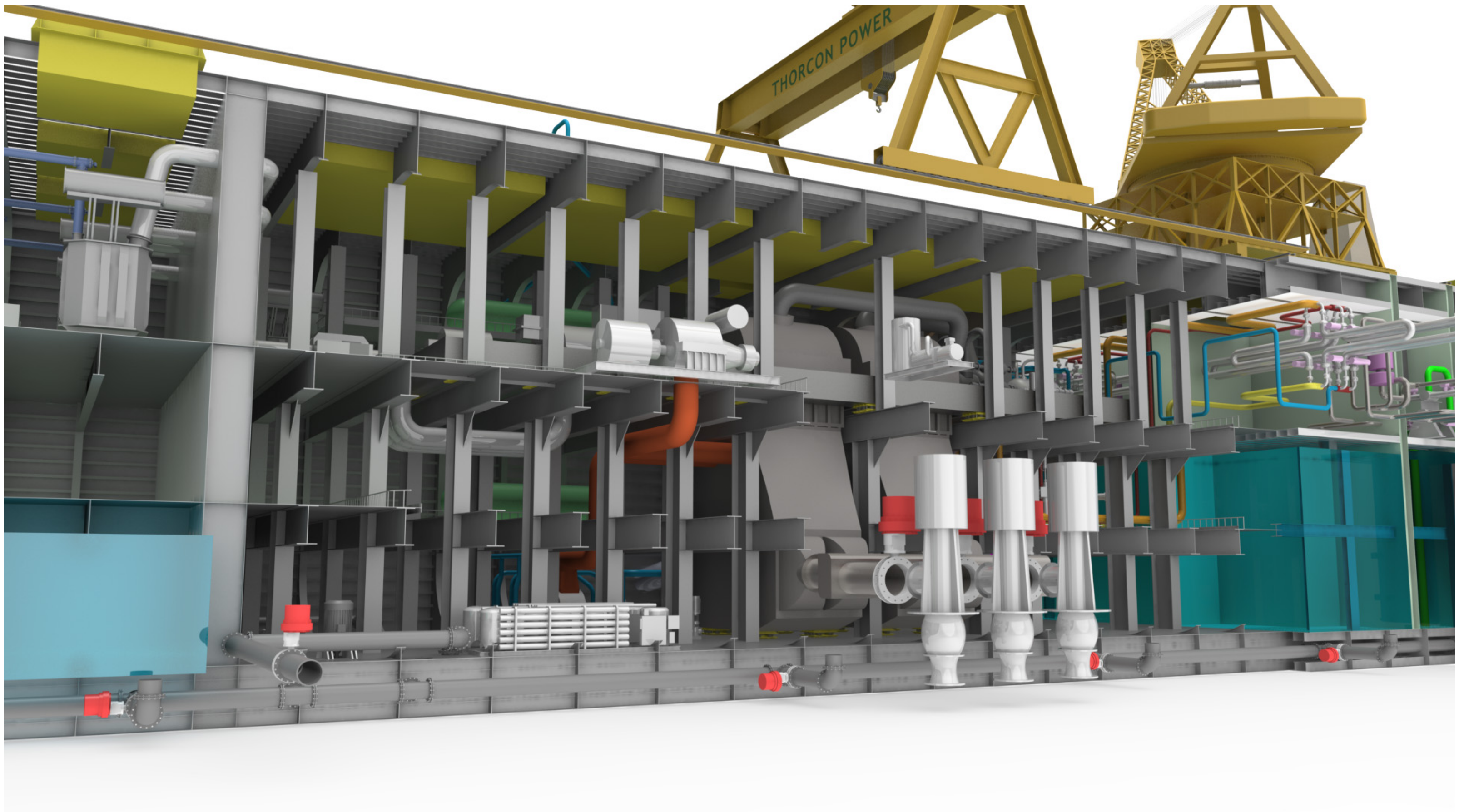


Figure 8: Turbine Hall Looking forward

1.2 Fission Island

Figure 9 is a cutaway view of the fission island. ThorCon is divided into 250 MWe power modules or PMODs. Figure 9 shows two such modules. Each module contains two replaceable reactors in sealed *Cans*. The Cans are depicted in red in the drawing. They sit in silos. At any one time, just one of the Cans of each module is producing power. The other Can is in cooldown mode. Every four years the Can that has been cooling is removed and replaced with a new Can. The fuelsalt is transferred to the new Can, and the Can that has been operating goes into cool down mode.

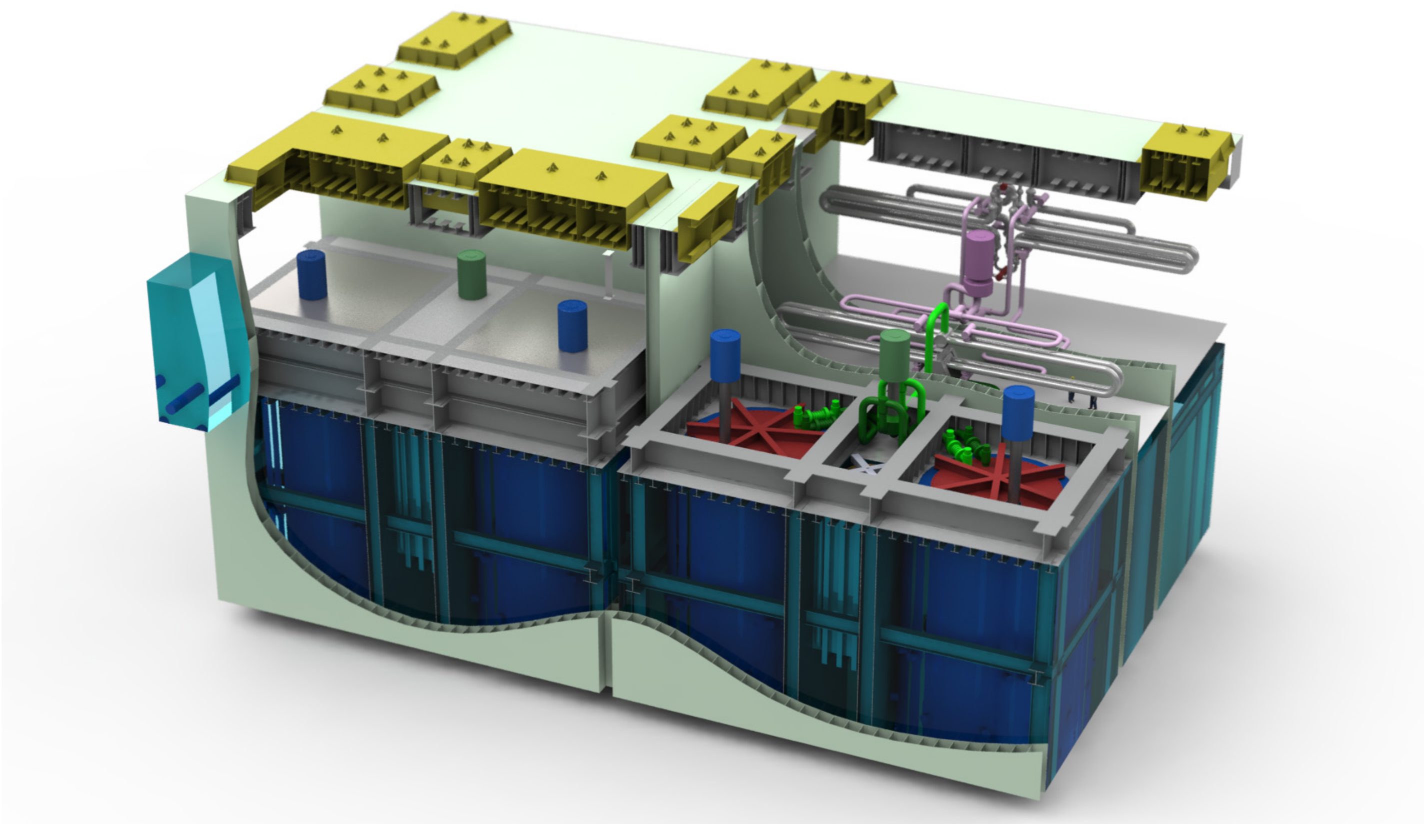
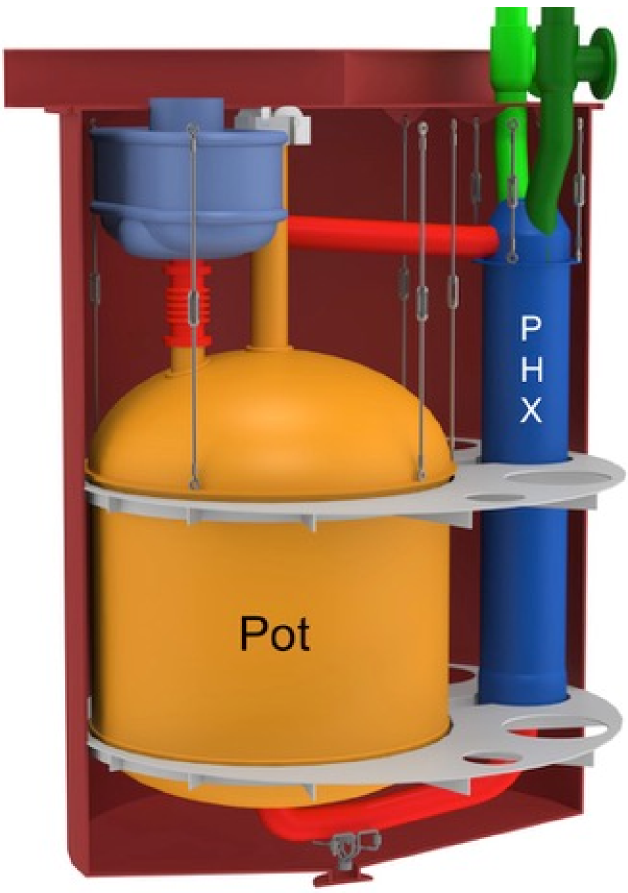


Figure 9: Cutaway view of two module Fission Island

The Can, Figure 10, is ThorCon's heart. The Can contains the reactor, which we call the *Pot*, a primary loop heat exchanger (PHX), and a primary loop pump (PLP).



Can thermal output	557 MW
Can electrical output	258 MW
Plant efficiency	46.3%
NaF-BeF2-ThF4-UF4	fuelsalt
76/12/10.2/1.8	mol pct
Vapor Pressure@704C	≤3 Pa
Fuelsalt flow kg/s	2934
Pot inlet C	565
Pot outlet C	704
Loop transit time	11.6 sec
Pot outlet press	2.9 barg
Can diameter	7.775 m
Can height	10.250 m
Pot diameter	4.916 m
Pot height	5.590 m
Can weight(no salt)	343 tons
Fuelsalt weight	43 tons
Fast α_K:pcm/K	-2/-3
Slow α_K:pcm/K	-5/-7

Figure 10: ThorCon Can: a Pot, a Pump, and a Still. Some components not shown for clarity.

The pump takes liquid fuelsalt — a mixture of sodium, beryllium, uranium and thorium fluorides — from the Pot at 704C, and pushes the fuelsalt over to the PHX at a rate of just under 3000 kg/s. Flowing downward through the PHX, the fuelsalt transfers heat to a secondary salt, and is cooled to 565C in the process. The fuelsalt then flows over to the bottom of the Pot, and rises through the reactor core, which is mostly filled with graphite blocks, called the *moderator*. This graphite slows the neutrons produced by the fissile uranium, allowing a portion of the uranium in the fuelsalt to fission as it rises through the Pot, heating the salt to 704C, and (indirectly) converting a portion of the thorium to fissile uranium. It's just that simple; and just that magical.

The Pot pressure is 3 bar gage, about the same as a garden hose. The outlet temperature of 704C results in an overall plant efficiency of 45%, and a net electrical output per Can of 250 MW. ***To produce this power, the Can requires only 39 liters of uranium per year enriched to 19.7%.*** The Can is a cylinder 11.6 m high and 7.3 m in diameter. It weighs about 400 tons. The Can has only one major moving part, the primary loop pump.

As shown in Figure 11, ThorCon employs four loops in converting fission heat to electricity:

1. The primary loop inside the Can
2. The secondary salt loop
3. A solar salt loop
4. A supercritical steam loop.

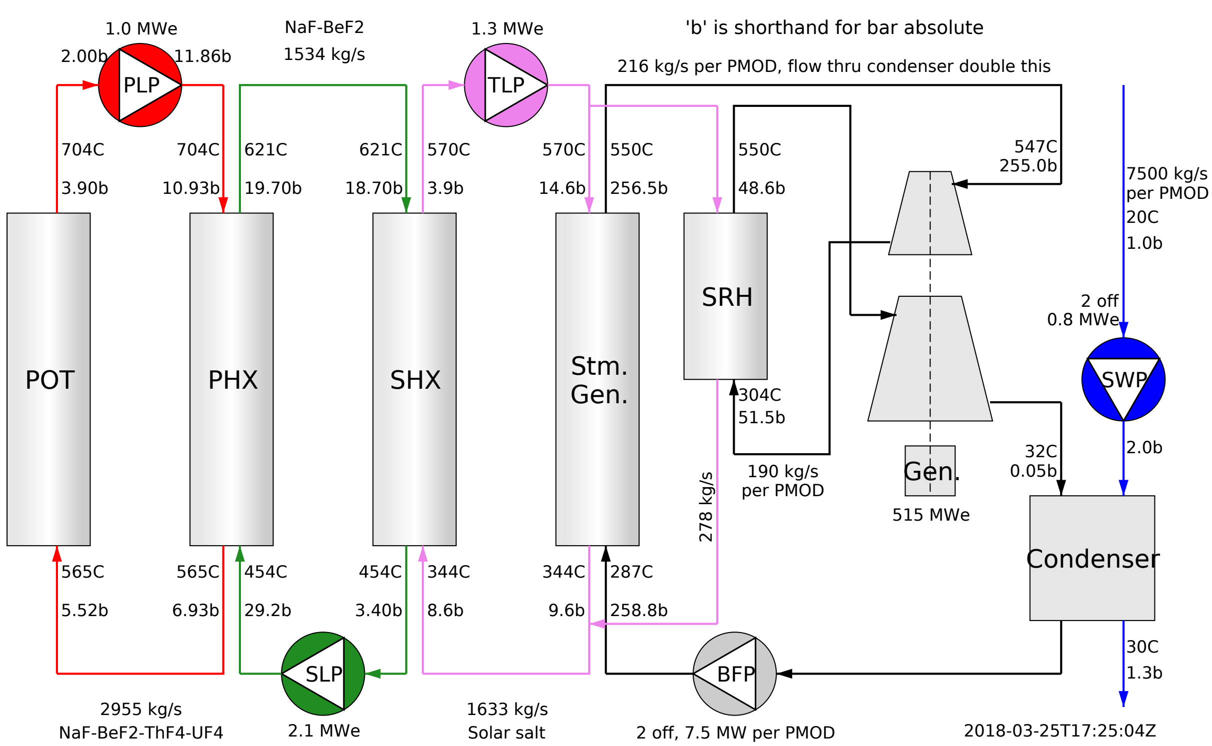


Figure 11: ThorCon's Four Loops. Feedheaters, etc not shown.

Figure 12 shows the piping. The secondary salt is a mixture of sodium and beryllium fluoride containing no uranium or thorium. Hot secondary salt, depicted in green, is pumped out of the top of the Primary Heat Exchanger to a Secondary Heat Exchanger where it transfers its heat to a mixture of sodium and potassium nitrate commonly called solar salt from its use as an energy storage medium in solar plants. The solar salt, shown in violet, in turn transfers its heat to a supercritical steam loop, shown in red and orange.

Unlike almost all current nuclear reactors, ThorCon is a high temperature reactor. This translates to thermal efficiency of 45% compared to about 33% for a standard light water reactor. This reduces capital costs and cuts cooling water requirements by 60%. It also allows us to use the same steam cycle as a modern coal plant.

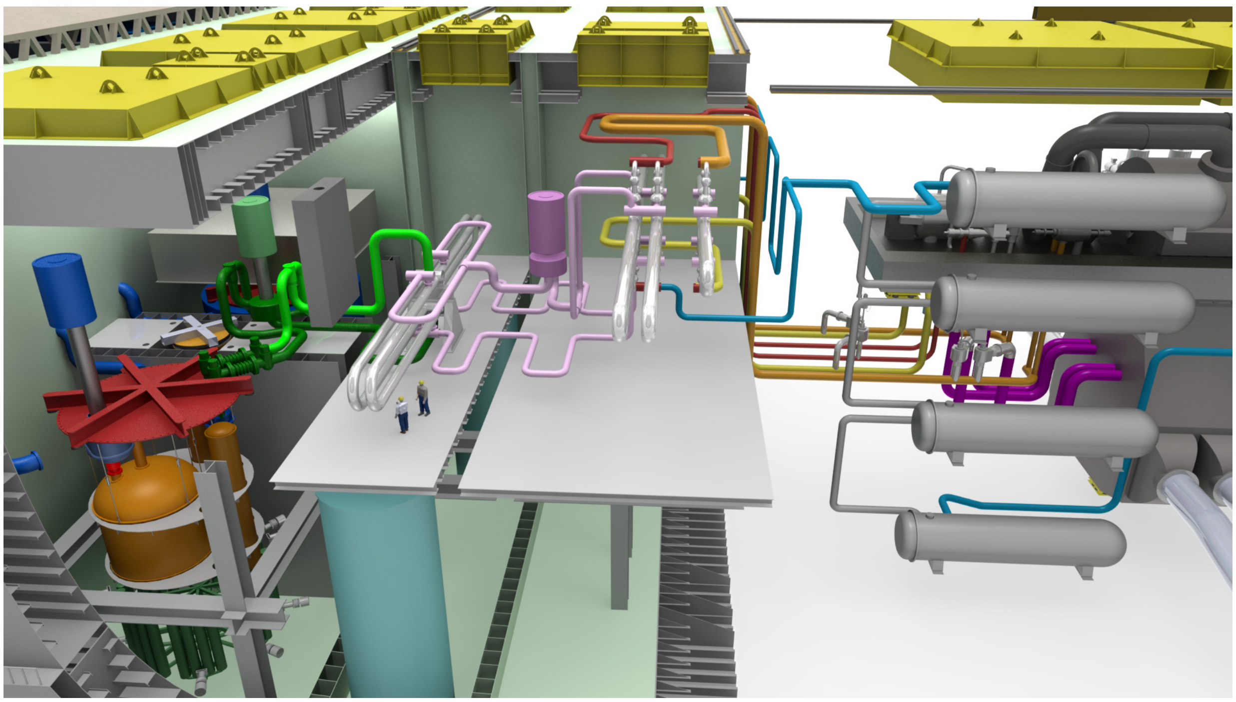


Figure 12: View of Salt Plumbing. Green is secondary loop; violet is solsalt loop.

Directly below the Can is the Fuelsalt Drain Tank (FDT), shown in green in Figure 13. In the bottom of the Can is a *freeze valve* shown in gray in Figure 13. The freeze valve is an insulated low point in the drain line. This valve is cooled by a flow of helium which freezes the fuelsalt in the valve creating a plug. The helium flow is controlled by a thermal switch which opens passively if the temperature at the top of the loop exceeds 750C. The plug then thaws and the fuelsalt drains to the FDT. Fission cannot take place in the drain tank since it has no moderator. This drain is totally passive. There is nothing an operator can do to prevent it.

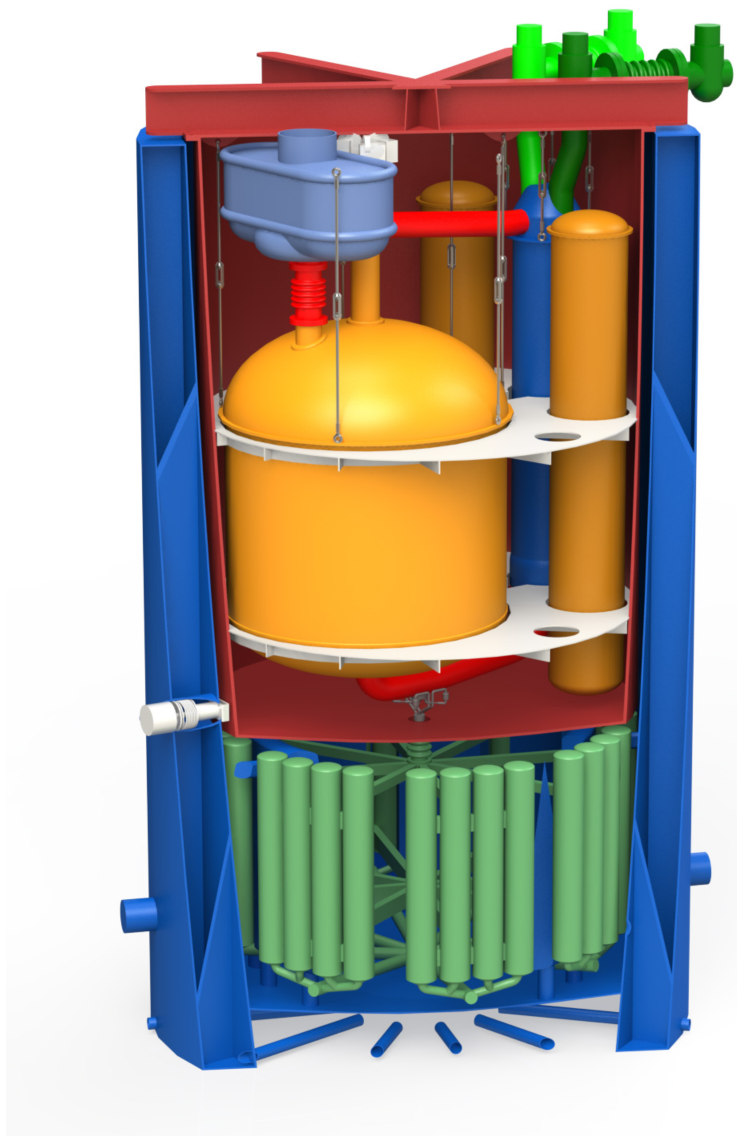


Figure 13: Can Silo

A critically important feature of ThorCon is the silo cooling wall or *cold-wall*. The cold-wall is made up of two concentric steel cylinders, shown in blue in Figure 13. The annulus between these two cylinders is filled with water. The top of this annulus is connected to a condenser in a decay heat pond located at the forward end of the Isle, as shown in Figure 14. The outlet of this condenser is connected to the *basement* in which the Can silos are located. This basement is flooded. Openings in the bottom of the outer cold-wall allow the basement water into the bottom of the annulus.

The Can is cooled by thermal radiation to the cold-wall. This heat converts a portion of the water in the wall annulus to steam. This steam/water mixture rises by natural circulation to the cooling pond, where the steam is condensed, and returned to the bottom of the cold-wall via the basement. In this process, some of the water in the pond is evaporated. The decay heat cooling towers keep the pond close to wet bulb temperature. If the pond cooling line is lost, there is enough water in the basement to handle the first 354 days of decay heat.

The cold-wall also cools the Fuelsalt Drain Tank (FDT). The drain tank is divided into a circle of cylinders. This arrangement provides sufficient radiating area to keep the peak tank temperature after a drain within the limits of the tank material. This cooling process is totally passive, requiring no operator intervention nor any outside power.

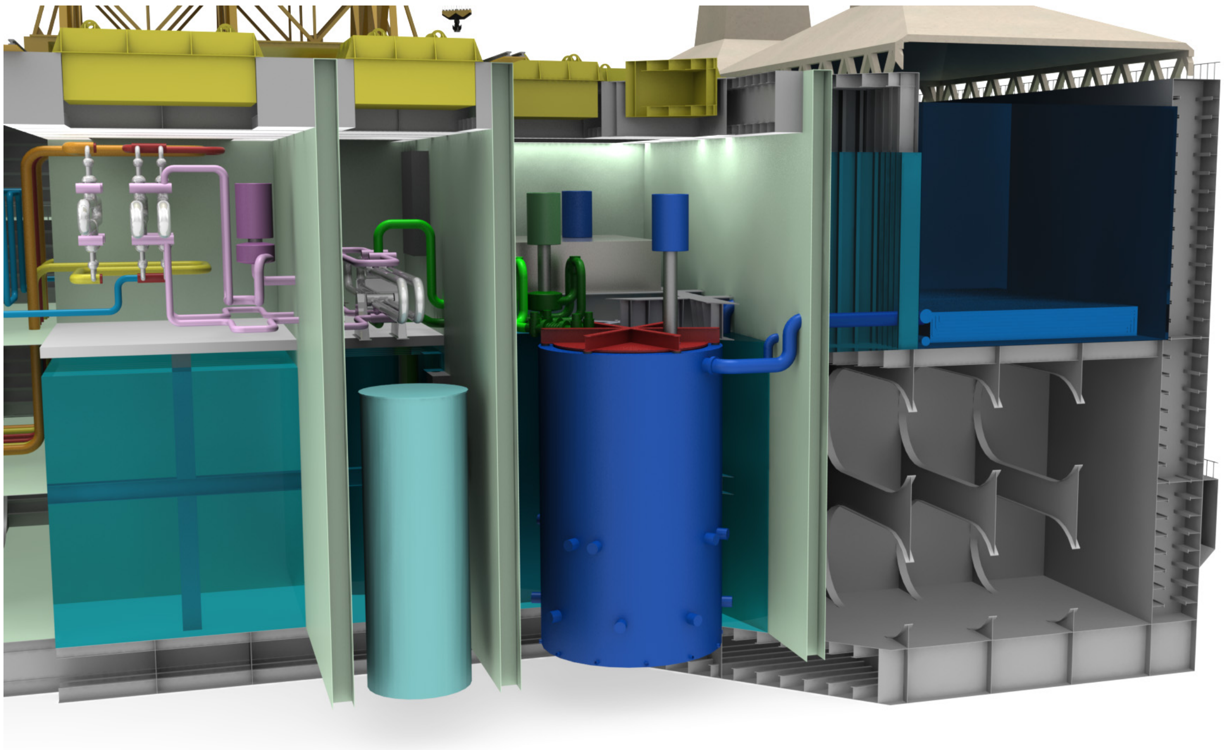


Figure 14: View of Cold-wall loop. Cold-wall piping shown in blue.

The cold-wall is what makes the ThorCon work.

1. The cold-wall allows us to keep the Can interior below 350C during normal operation. and keeps the Can from over-heating after a drain.[1] The fact that the cold-wall is always operating is an important safety feature. If a problem develops in the cooling wall loop, we will find out before a casualty occurs rather than during.
2. The wall allows us to capture any tritium permeating through the Can or drain tank in the inert gas in the annulus between the Can/FDT and the walls.
3. The wall cools more rapidly as the Can/FDT tank heats up, but more slowly as the Can/drain tank cool down, which is exactly what we want to handle both emergencies and avoid salt freeze ups.
4. The wall maintains a double barrier between the fuelsalt and the cold-wall water, even if the primary loop is breached.
5. And the cold-wall does all this without any penetrations into the Can or the fuelsalt drain tank.

[1] Some fission products remain in the primary loop even when it is drained.

2 Walkaway Safety

Totally passive, totally unavoidable shutdown and cooling ThorCon combines a strongly negative temperature coefficient with a massive margin between the operating temperature of 700C and the fuelsalt's boiling temperature (1430C). As the reactor temperature rises, ThorCon's power output drops. This is an intrinsic, immutable property of the reactor physics. ***In any casualty that raises the temperature of the salt much above operating level, ThorCon will shut itself down.***

If the high temperature persists, the freeze valve will thaw and drain the fuel from the primary loop to the drain tank, where the silo cold-wall will passively handle the decay heat.

There is no need for any operator intervention. Not in 3 days, not in 300 days, not in 3000 days. Nor are there any valves that must be realigned by either system or operator control as in some so called passive systems. In fact ***there is nothing the operators can do to prevent the shutdown, drain, and cooling***.

Release Resistant ***ThorCon has at least three gas tight barriers between the fuelsalt and the atmosphere.*** Figure 15 shows a sectional view of the hull in way of the fission island. The structure is similar to the cargo hold section of a large tanker with a 3 meter wide double bottom and double sides. In addition, a 3m deep double roof is provided in way of the fission island. The double sides and roof are filled with concrete. This is an extremely strong structure. It will not be penetrated by a Boeing 777 engine in a perpendicular impact at 250 knots. The hull which is a double barrier is only one of at least three gas tight barriers between the the fuel salt and the atmosphere. The Can silo is a gas tight structure; and the Can itself is a gas tight structure. All these must be breached to allow a release.

But even if they were, there is no internal dispersal mechanism. The ThorCon reactor operates at near-ambient pressure. In the event of a primary loop rupture, there is little pressure energy and no phase change. The spilled fuel merely flows to the drain tank where it is passively cooled.

Moreover, the most troublesome fission products, including iodine-131, strontium-90 and cesium-137, are chemically bound to the salt. They will end up in the drain tank as well.

No separate, spent fuel storage ThorCon uses an 8 year fuelsalt processing cycle, after which the used salt is allowed to cool down in the non-operating Can for four years, ***eliminating the need for a separate, vulnerable spent fuel storage facility.*** The fuelsalt that is cooling is as well-protected as the fuelsalt that is currently being burned.

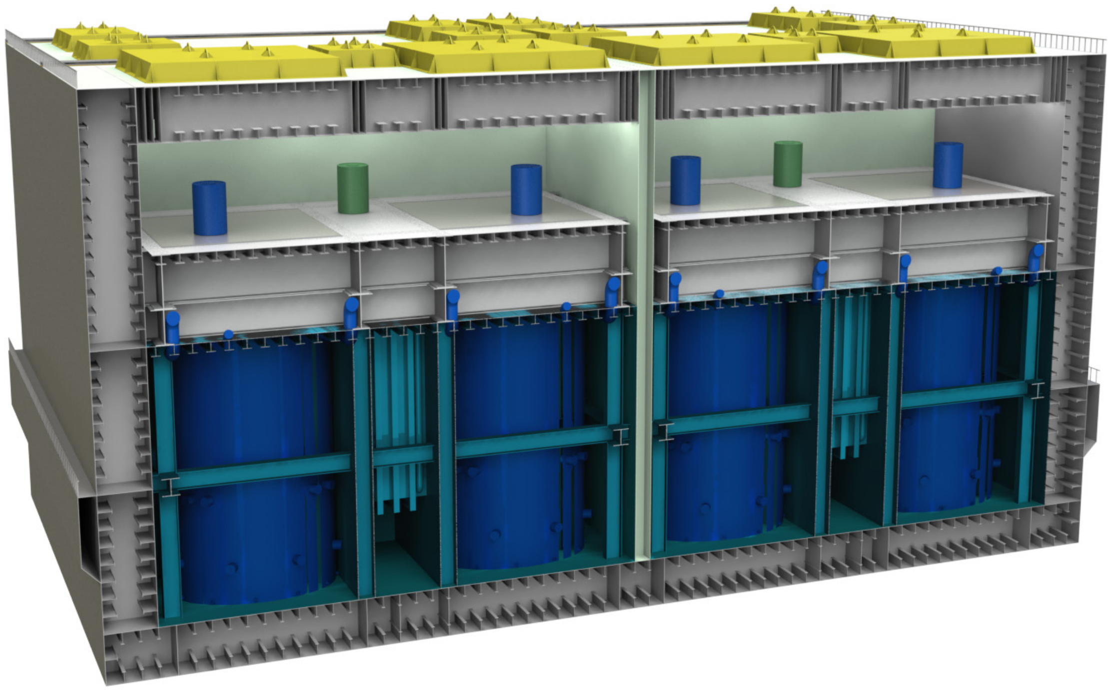


Figure 15: Fission Island looking aft.

Four loop separation of steam and fuelsalt. ThorCon employs four loops in transferring heat from the reactor to the steam turbine.

1. The primary fuel salt loop
2. The secondary fluoride salt loop
3. A solar salt loop. This is the same salt used in thermal solar plants.
4. A high pressure steam loop

The solar salt loop captures any tritium that has made it to the secondary loop, and more importantly ensures that a rupture in the steam generator creates no nasty chemicals and harmlessly vents to the Steam Generating Cell via an open standpipe.

3 Shipyard productivity, shipyard quality

To supply the electricity that the emerging economies so desperately need, we will require 100 one GWe ThorCons per year for the foreseeable future. And we need them soon. We need a ***system*** for producing fission power plants, not individual fortresses. Fortunately such a system exists. It's called a shipyard.

ThorCon's genesis is in ship production. Figure 16 shows one of eight ships built by ThorCon's predecessor company. This ship is the largest double hull tanker ever built. She can carry 440,000 tons of oil. Her steel weight is 67,000 tons. She required 700,000 man-hours of direct labor, a little more than 10 man-hours per ton of ship steel. About 40% of this was expended on hull steel; the rest on outfitting. She was built in less than 12 months and cost 89 million dollars in 2002.

Figure 16: The Hellespont Metropolis, 500,000 tons on the move, 89 million dollars

A good shipyard needs about 5 man-hours to cut, weld, coat, and erect a ton of hull steel. The yards achieve this remarkable productivity by block construction. Sub-assemblies are produced on a panel line, and combined into fully coated blocks with piping, wiring, HVAC (and scaffolding if required) pre-installed. In the last step, the blocks, weighing as much as 600 tons, are dropped into place in an immense building dock.

Block construction is not just about productivity. It's about quality. Very tight dimensional control is automatically enforced. Extensive inspection and testing at the sub-assembly and block level is an essential part of the yard system. Inspection at the block level can be thorough and efficient. Defects are caught early and can be corrected far more easily than after erection. In most cases, they will have no impact on the overall project schedule.

ThorCon is designed to bring shipyard quality and productivity to fission power. But ThorCon's structure is far simpler and much more repetitive than a ship's. The fission island employs concrete-filled, steel plate, sandwich walls. This results in a strong, air-tight, ductile building, all simple flat plate. A properly implemented panel line will be able to produce these blocks using less than 2 man-hours per ton of steel.

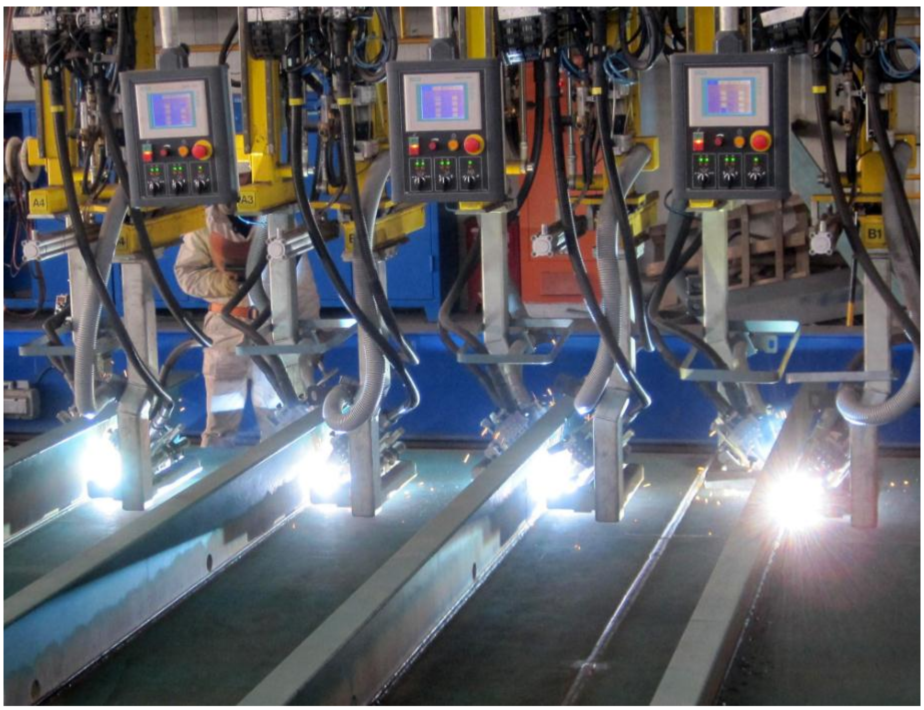


Figure 17: Shipyard Productivity, 5 man-hours per ton of erected steel

4 Small is beautiful

Fission power is one million times denser than fossil fuel. Not only does this mean that fuel requirements (and waste) for a big power plant are measured in kilograms per day rather than thousands of tons per day; but it also means that, if you operate at low pressure, the plants can be small. The ThorCon reactor operates at near ambient pressure. ThorCon does not need much space. Nor does it consume a lot of resources.

In fact, a 1 GWe ThorCon is so small that the fission island almost fits into two center tanks of the Hellespont Metropolis, and requires one-fourth as much steel.

The steel weight of a 500 MW ThorConIsle is about 50,000 tons. The world's largest shipyard can build more than 2,000,000 steel tons of ships per year. A single shipyard can produce 20 GW's of ThorConIsle power per year. In terms of resource requirements, one gigawatt of ThorCon power is not a big deal. The scale up rate will not be limited by the fission island side, but by the rate at which the turbogenerators can be built.

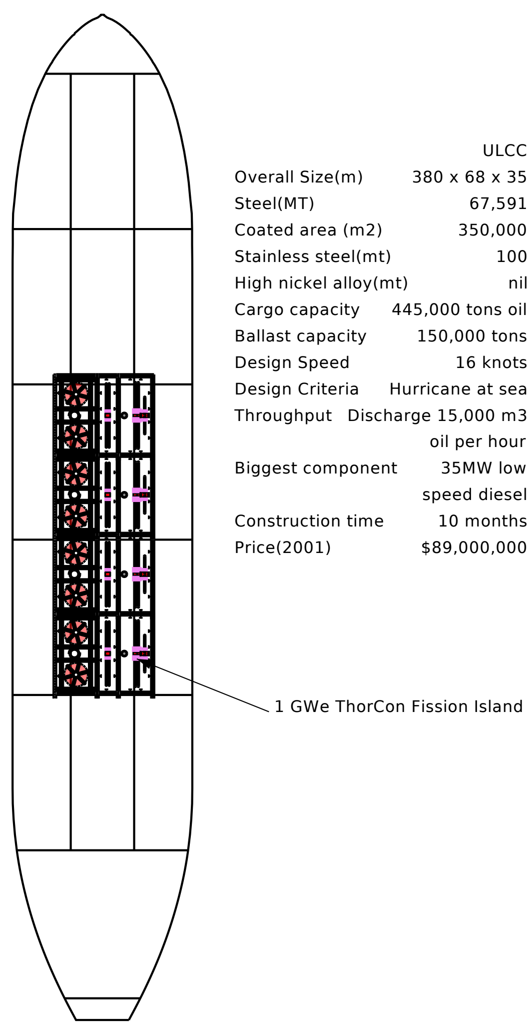


Figure 18: 1 GW ThorCon Fission Is. in a very large tanker

5 If it breaks, send it back

In the ThorCon system, no complex repairs are attempted on site. Everything in the fission island except the hull itself is replaceable with little or no interruption in power output. Rather than attempt to build components that last 40 or more years in an extremely harsh environment with nil maintenance, ThorCon is designed to have all key parts regularly replaced.

Up to 50 ThorCon plants are supported by a Centralized Recycling Facility (CRF) and a separate Fuel Handling Facility (FHF). Normally, the Cans are changed out every four years. When the Cans need replacing, they are shipped to the CRF in a special purpose Canship. Figure 19 shows a Can being transferred to the Canship. At the CRF, the Cans are disassembled, cleaned, inspected, and worn parts replaced. The problems of decontamination and waste disposal are shifted from the plant to this facility.

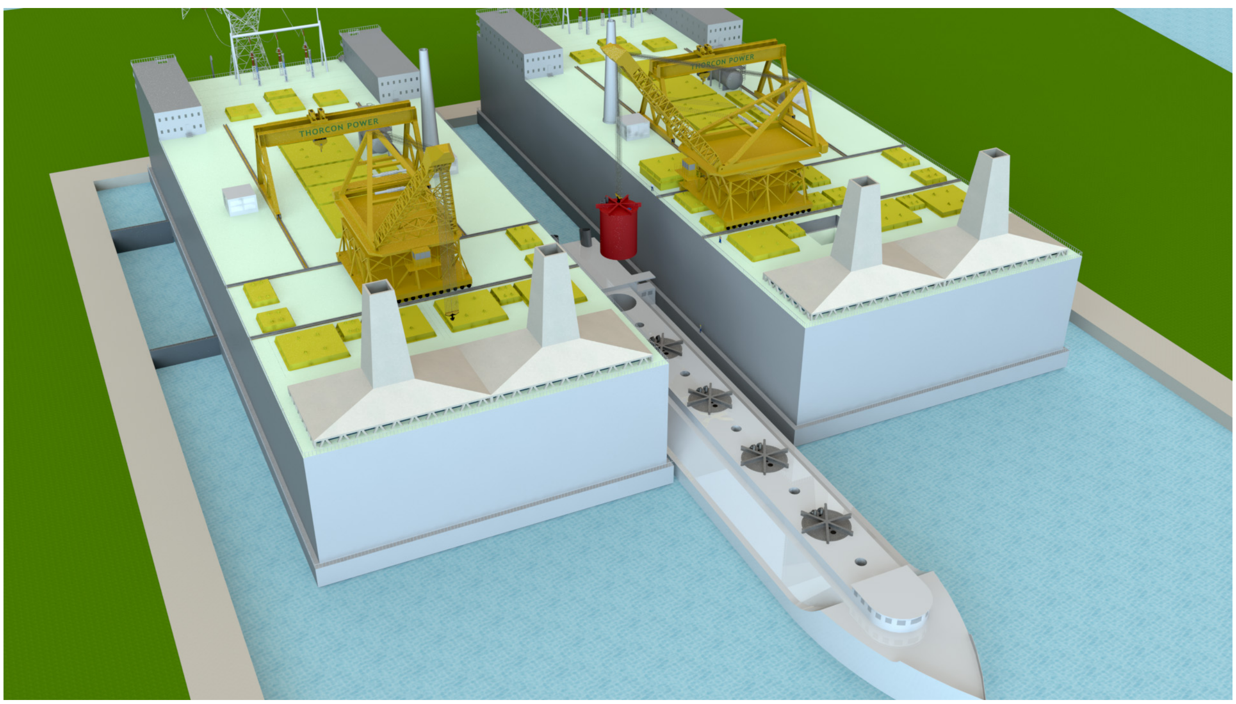


Figure 19: Cooled Can being lowered into a Canship

After eight years of operation, the build up of fission products will require us to change out the fuelsalt. The old fuelsalt will remain in its Can for four years. During this cool down period, the old fuelsalt is as well protected as the salt in the operating Can. There is no need for a separate, vulnerable spent-fuel cooling and storage system. By the time we pump the old fuelsalt to a shipping cask, its decay heat will be down to 80 kW, 0.25% of the original. The casks will then be transferred to the FHF in the Canship.

The fuelsalt going both ways will be unattractive weapons material. The uranium will be fully denatured. The returning plutonium will be reactor grade. More importantly, it will be mixed with 50 times as much neutron absorbing thorium. Such a mixture cannot go critical. To produce even a weak fizzle weapon, the plutonium must be separated from the thorium. This is an extremely difficult process requiring a Thorex plant. Currently, no such plant exists. ThorCon's fuelsalt will be far more proliferation resistant than the MOX fuel which is currently being shipped from France to Japan.

This system of regular replacement of the most critical components means that major upgrades can be accomplished without significantly disrupting power generation. And since the returned Cans are disassembled and fully inspected, incipient problems will be caught before they can turn into casualties.

Such renewable plants can operate indefinitely; but, if a ThorCon is decommissioned, the process is little more than pulling out but not replacing all the replaceable parts.

6 Unless you are cheaper than coal, don't bother

ThorCon produces the same high temperature steam as a modern coal plant, and uses the same power conversion equipment — the same turbine hall and switchgear — as a standard supercritical coal plant. This equipment is nearly off-the-shelf and can be purchased for about $500/kW from a half-dozen or more vendors. But on the steam generation side, the 5000 ton per day coal handling system, the massive boiler, flue gas treatment, and ash handling system, Figure 20, are replaced by the fission island. Figure 21 makes the point that ThorCon's fission island is tiny compared to the coal plant's boiler and all its associated gear.

Table 1 compares the steel and concrete requirements of a 500 MW ThorConIsle with that of a coal plant of the same capacity. Power conversion is a wash. However, the ThorCon fission island requires one-seventh as much steel as the coal plant boiler, fuel handling, and ash handling systems. ThorConIsle gives most of this back in the steel intensive hull.

Table 1: Steel and Concrete for a 500 MW Plant

	ThorCon		Coal	
	Steel	Concrete	Steel	Concrete
Hull	40,000	29,000		
Steam Generation	8,000		55,000	81,000
Power Conversion	14,000		14,000	26,000
Total	64,000	29.000	67,000	107,000

Overall, the ThorConIsle requires less steel and one-third the concrete of the same size coal plant. Moreover, almost all the ThorCon concrete is non-structural, simply dumped into the steel sandwich walls; while a large part of the coal plant concrete is slow, labor intensive, reinforced concrete. Further the bulk of ThorConIsle steel is simple flat plate panels which shipyards can produce and erect for less than $1000 per ton. Finally almost all the ThorCon work is done in a controlled assembly line environment. Almost all the coal plant work is done on site.

The ThorCon steam generation side does require some costly items that a coal plant does not need. A ThorCon fission island requires 700 tons of very high quality graphite, and 760 tons of SUS 316. But these and other adjustments add a little more than 50 million dollars to the cost of a 500 MW plant or about $100/kW. Overall the resource cost of the ThorCon fission island is less than one-half that of the coal plants steam generation systems, less than $500 per kW. Assuming efficient regulation, ThorCon's capital cost will be cheaper than coal.

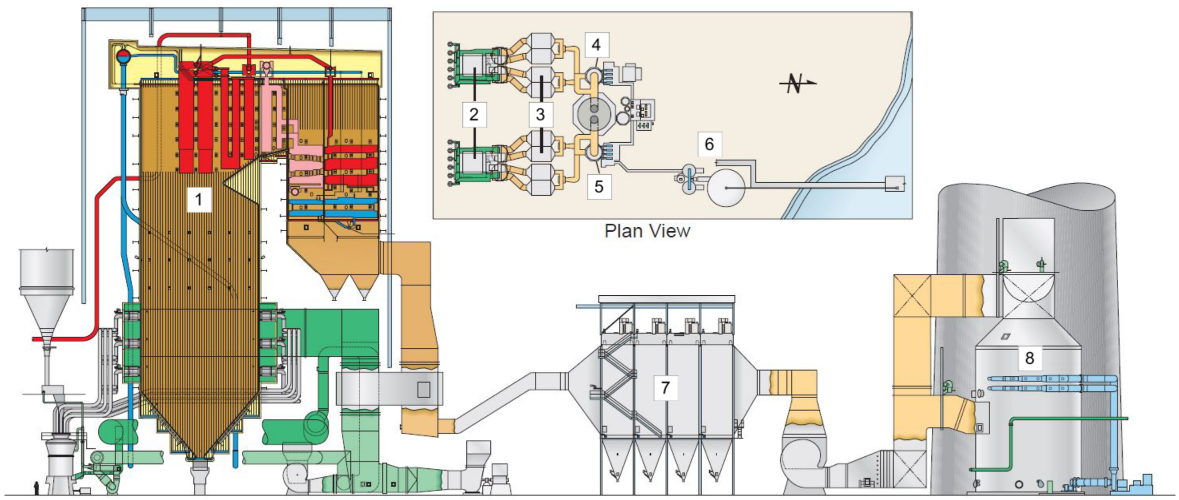


Figure 20: 660 MW Tanjung Jati boiler and gas handling equipment. 1. Furnace, 2. boiler house, 3,7. Electrostatic Precipitators (modern baghouse), 4,5,8 scrubbers, 6. wet scrubber limestone silo

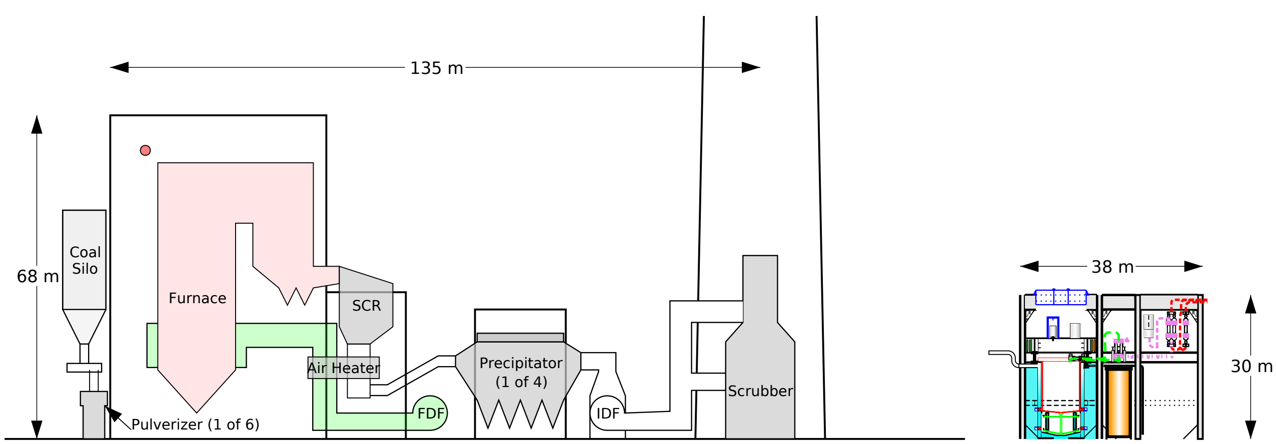


Figure 21: Coal steam generation vs ThorCon steam generation

7 Five Kilos of Fuel per Day

ThorCon is a thorium converter. The initial fuel charge is largely thorium. During the eight year fuel cycle, a portion of the fertile thorium is converted to fissile U-233 which then becomes part of the fuel. Table 2 shows the fuel requirements of a 250 MW ThorCon Power Module. This figure makes the point that ThorCon's fuel consumption is measured in kilograms per day. Each ThorConIsle will require 5.2 kg of 19.7% enriched uranium and 8.8 kg of thorium per day.

One result is that ThorCon clobbers coal on fuel cost. An extreme lower bound on coal fuel cost is 2 cents per kWh. Table 2 shows that at $90/kg U3O8, about double the current yellowcake spot price, ThorCon's fuel cost is less than 0.4 cents per kWh.

Table 2: Once through fuel costs per 250 MW Power Module

ThorCon Version:: 1.26			2018-04-11T20:19:14Z
Discount rate (pct):	10.00	Capacity factor:	1.00
Fuel U235 percent:	19.700	Feed U235 percent:	0.720
Tails U235 percent:	0.20	Feed kg per fuel kg:	37.50
U3O8 USD per lb:	40.82	U3O8 USD per kg:	90.000
USD per SWU:	50.00	U3O8 to UF6 per kg:	7.50
U308 USD per kg of U235:			20203.26
Conversion USD per kg of U235:			1427.66
SWU USD per kg of U235:			11325.65
U235 USD per kg:			32956.58
Thorium USD per kg:			50.00

Year	Initial Inventory U-235 kg	Makeup Fuel U-235 kg	Thorium Th-232 kg
0	466	494	12914
1	0	0	0
2	0	0	0
3	0	0	0
4	0	542	0
5	0	0	0
6	0	0	0
7	0	0	0

Present valued cost of U235, million USD:	43.839
Present valued cost of thorium, million USD:	0.646
Levelized USD per kWh:	0.00346
Gross value of final 331 kgs of U235 million USD:	10.92
Total U feed kg:	285914
Total U235 kg:	1502
End inventory U235 kg:	331
End inventory U233 kg:	204
Net fissile consumed kg:	966

Figure 22: All the waste from 450 MW's for 28 years. If coal plant ash for the same energy was placed on this pad, it would be a column 2000 m high.

8 A Beautifully Small Problem

The nuclear waste problem is largely a political construct. The volumes are tiny and easily shielded. The "waste" can be valuable. And after a few hundred years, it is fairly easily handled since almost all the penetrating gamma radiation will be gone. The remaining radiotoxicity is almost all alpha which must be ingested or inhaled in order to do harm. Since almost all the alpha emitters are in ceramic form, e.g. plutonium oxide, this would require eating rocks. The amounts are so small that, if the USA went all fission using light water reactors and recovered none of its high level waste, the country would need to allocate 80 hectares of desert every 20 years for dry cask storage. As McKay puts it, nuclear waste is a "beautifully small" problem.

Figure 23 is a sketch of the fuelsalt flows for one 500 MW ThorConIsle for one year. The black numbers are once through. Since ThorCon's spent fuel after 8 years is 8.6% enriched in U235 and U233, this would be wasteful. The green numbers assume the uranium in the spent fuel is separated by fluoride volatility, a process used every day in uranium enrichment, and then re-enriched to 19.7%. This re-enrichment takes only 4.5 SWU/kg product. and reduces ThorCon's requirement for mined uranium by about one-third.

On average, each Isle will send one cask to storage every two years. These casks are about 3 meters in diameter. A single hectare can store 125 GW-years worth of these casks. If for example Indonesia went all ThorCon power, she would have to devote a hectare of space every

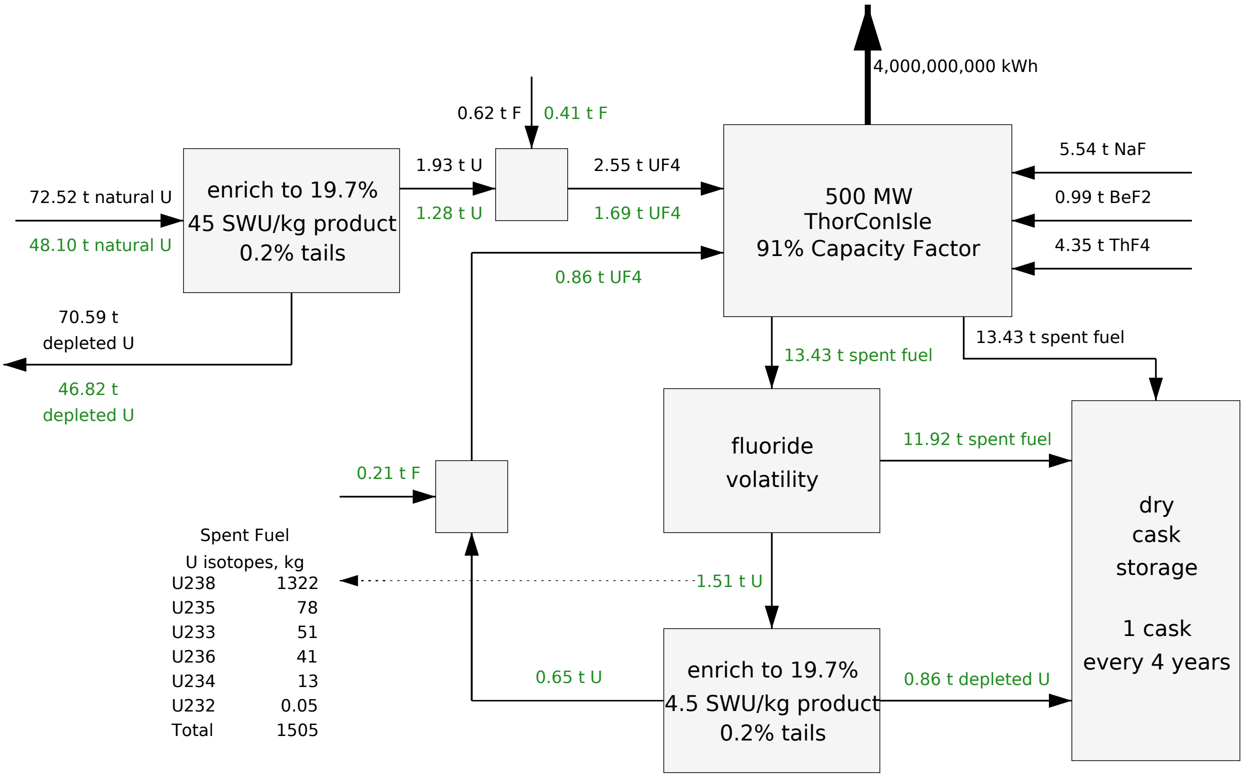


Figure 23: Fuelsalt flows in metric tons, one Isle for one year. Black is once through. Green is recycle uranium. Flows are averaged over 8 years.

6 years to cask storage.

In contrast, a typical 1 GWe coal plant produces roughly 300,000 tons of solid waste annually. This ash is much lighter than ThorCon solid waste, roughly 1000 kg/m3 in bulk form. In terms of volume a coal plant produces over 100,000 times more solid waste per kWh than ThorCon.

The important arrow in Figure 23 is the thick one, which shows that each ThorConIsle will produce 4,000,000,000 kWh of non-intermittent, dispatchable, pollution-free, CO2-free electricity each year. That is enough power to support 500,000 people at better than European standards. The remarkable fact is that an Isle does this while producing waste flows that are measured in a few tons per year.

9 A Race We Must Win

Currently mankind consumes electricity at a rate of about 2,300 gigawatts. But the distribution is horribly uneven as Table 3 shows. The USA averages 1,400 watts per person. The Scandinavian countries considerably more. But most of Latin America is below 250 W. Most of South Asia below 100 W. Most of Africa below 25 W. And the national averages mask wide disparities. Over a billion humans have no access to electricity at all. ***If humanity is to prosper, then affordable, dependable power must be available to all.*** And we must provide this power without polluting the air we breath, without poisoning the land we live on, and without impacting the climate we depend on.

	watts/person		watts/person
Norway	2,922	Mexico	208
USA	1,401	Egypt	163
Australia	1,064	Iraq	125
Russia	831	Columbia	113
France	815	Indonesia	92
Germany	772	India	65
Italy	582	Philippines	61
South Africa	550	Angola	28
China	396	Nigeria	13
Iran	261	Afganistan	9
Brazil	258	Haiti	3

Table 3: Electricity consumption per person

The developing countries are aggressively moving to close the power gap. This will require at least 2,000 gigawatts of new capacity over the next 20 years, or 100 one GW plants per year, about 2 per week. As things stand now, most of these plants will be coal fired. According to the MIT Technology Review, 1,199 coal plants are planned worldwide, with a nameplate capacity of 1,401 gigawatts. In aggregate, these 1200 new coal plants will burn 5 billion tons of coal per year, produce 500 million tons of solid waste annually, kill or shorten the lives of at least 400,000 people per year, and spew 12 billion tons per year of CO2 into our children's troposphere.

ThorCon offers an alternative,

- an alternative that produces nil pollution, nil CO2, and 100,000 times less waste than coal,
- an alternative that uses dramatically less of the planet's precious resources, less steel and less concrete than coal,
- an alternative that requires no technological breakthroughs.

A fullscale 500 MW ThorConIsle prototype can begin testing in four years, commercial deployment can start in six years, and with shipyard productivity and using current shipyard capacity we can be churning out 100 GW's of ThorCons annually within ten years. All we have to do is to decide to let it happen.

It's our choice.