ThorCon™

the Do-able Molten Salt Reactor

Safeguards and Security

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Version: Version: 1.31
Date: 2019-12-09

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1 The Three Threats

The fissile material in a nuclear power plant poses three rather different threats:

1. Possible use by the host nation aimed at acquiring nuclear parity or better with existing weapons states. For this purpose, the proliferant country needs a reliable, high yield weapon. ThorCon should ensure that the composition of the fissile material is such that the processing required to upgrade the material is so difficult that the proliferant state will choose another pathway even if they have ThorCons operating in their territory. ThorCon must also impose a fuel accounting system which will catch any successful diversion of the material.
2. Theft by a sub-national group aimed at blackmailing or terrorizing its opponents. For this purpose, even a very low yield device may suffice. ThorCon must ensure that the fuel is difficult to steal and impossible to remove without being discovered. ThorCon also must enure that, if the fuel is stolen, the composition is such that even a very low yield device is infeasible without advanced processing capabilities.
3. Capture of the plant by a sub-national group with the goal of terrorizing the surrounding area by “blowing it up” and causing a release of radioactive material.

To understand how ThorCon counters these three threats, it is necessary to understand how ThorCon handles fissile material. For those unfamiliar with the ThorCon design, the document ThorConIsle: Doable, Movable Power, should be read prior to reading the main body of this document.

2 ThorCon Proliferation Resistance and Fuel Protection

2.1 Fuel accessibility

In a ThorCon power module (PMOD), fissile material is found in four places:

1. the operating fuelsalt,
2. the spent fuelsalt being cooled (half the time),
3. the makeup fuelsalt,
4. and a bit in the used flush salt.

Except during refueling, all this material is below the silo hall deck in an inerted, very high radiation environment. ***No access to this area is possible while a PMOD is operating.*** Figures 1 and 2 show the layout.

The makeup fuelsalt for each Can is in its own tank inside the Can. This tank is filled at the Can Recycling Facility (CRF) and the Can is then sealed. The flush salt is in one of the flush salt drain tanks also below the silo hall deck. During refueling, the fuelsalt or the flush salt is transferred via a 310 ton Fuelsalt Transfer Cask which is also located below the silo hall deck.

The only access to this area is through the heavy silo hall deck hatches which form part of the radiation barrier. In the case of the Can silos, the "hatch" is actually the radtank. So the radtank must be drained, and even drained the radtank is a 350 ton lift which barely fits through the surface hatch.

If this is done with an empty, uncooled Can, the gamma dose at the Can wall will be about 3 Sv/h. 3 sieverts over a short period is about LD50 dose. If the Can were not emptied, the gamma dose rate would be 150 times higher. The crane capacity required is in excess of 400 tons.

But there is no crane in the silo hall. So the silo main deck hatch must be removed to give access to the silo hall deck by the whirley crane. This is also a 300 ton lift. Alarms and video cameras are placed on both the main deck and silo hall deck hatches. Some of this surveillance system can be placed below the silo hall deck which will require lifting the hatches to tamper with the sensors. There will be an encrypted, one way link between each ThorCon plant and a trusted authority, presumably the IAEA. This link would transmit not only the plant sensor data to the trustee but pictures from the surveillance TV's as well. The most important data and pictures could be put on the Internet for all to see.

There is no access between power modules. Removal of the hatches, and lifting of the Casks and Cans to the surface is detectable by satellites. This use of satellites probably requires a tripwire. Satellites are limited resources and cannot be assigned to continuously stare at a particular plant. However, if any alarm bell goes off, for example, the data link goes down or appears compromised, satellites can confirm or deny a hatch opening and provide the smoking gun for international response.

One obvious response to an attempted diversion is to disable the whirley crane. Unlike the rest of ThorCon fission island, the above deck whirley crane is a soft target, easily taken out by

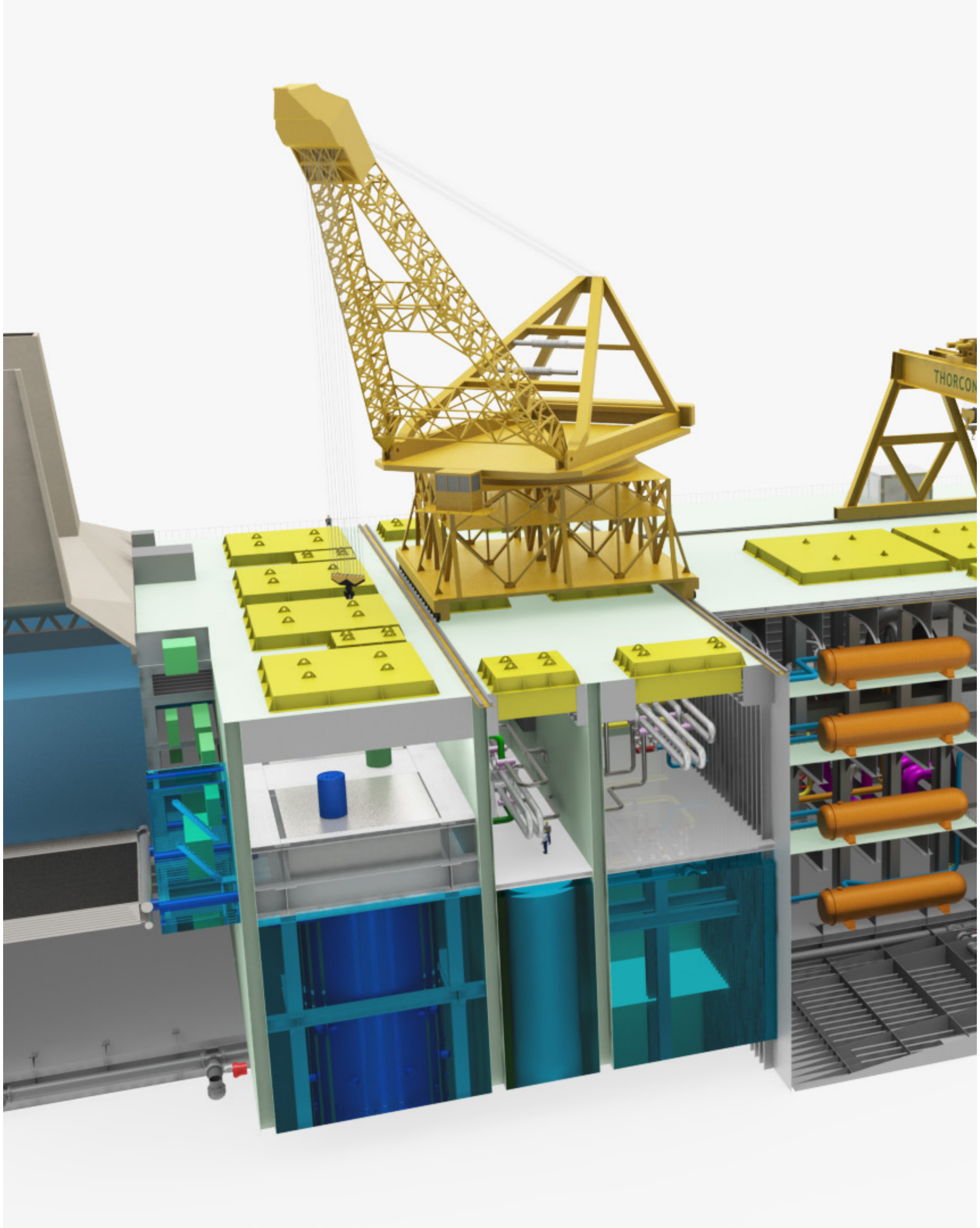

Figure 1: View of Power Module with Crane.

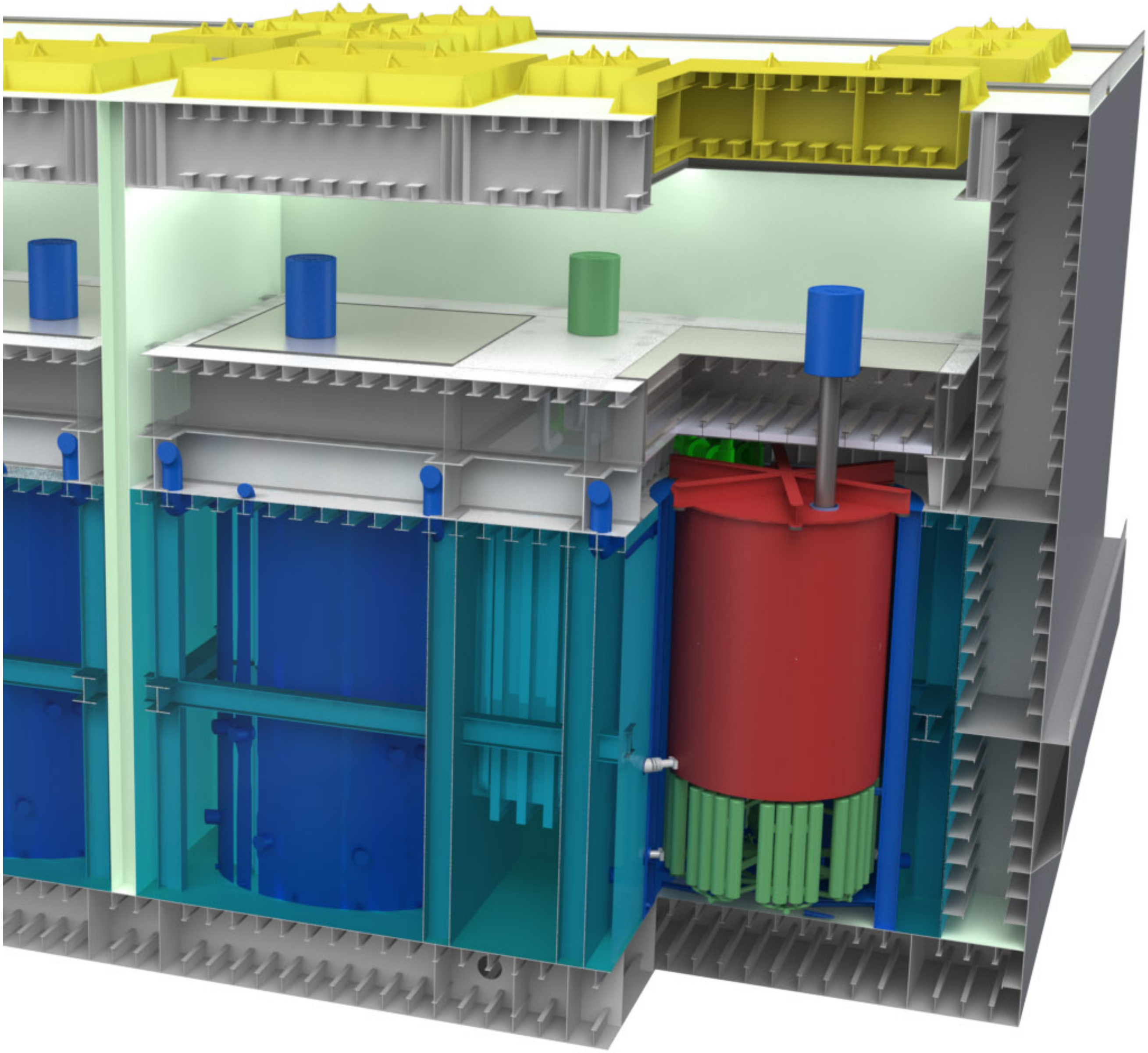

Figure 2: Section of Power Module. Can shown in Red.

a drone using modern weapons without a great deal of damage to the rest of the plant. Without the crane, accessing the fuel becomes far more difficult.

In short, except during Can and Fuelsalt change outs, the ThorCon fissile material is at least as inaccessible as light water fuel elements. Any attempt to remove fuel from a power module will require an extended shutdown of the module, and multiple multi-100 ton lifts which would be caught by even the most rudimentary surveillance system.

2.2 No On-site Fuel Processing

The international regulatory system makes a sharp distinction between the consumption of fissile material and its production. The ThorCon design is consistent with this distinction. In the ThorCon system, no fuel processing is done at the plants.[1] Any such processing is only done when the spent fuel is returned to the Fuelsalt Handling Facility, which if necessary can be located in a weapons state. This eliminates one obvious diversion path.

2.3 Little On-site Construction

The Safeguards system must ensure that each plant is built per approved design. This will be facilitated by the fact that not only are all ThorCon fission islands identical, but that they are built in a shipyard where they will be easily inspected. The only thing that happens on site is the hull is ballasted to the seabed and connected to the grid. Just prior to first fuel delivery, IAEA can do a final inspection to confirm that the major changes required to insert an extraction system have not been done. If the plant fails this inspection, the initial fuel will not be delivered.

2.4 Fuel Accounting

Every four years a Canship brings in new Cans. The old Cans are emptied, flushed, and returned to the Can Recycling Facility (CRF). Every other four years fresh fuelsalt is brought in and the spent salt which has cooled for four years is returned to the Fuelsalt Handling Facility (FHF) in a 310 ton fuelsalt transfer cask. In the intervening four years, the flush salt is returned to the FHF in the same kind of cask. Each CRF and FHF can support at least fifty 1 GW ThorCon power plants. The Fuelsalt Handling Facility must be a trusted facility.

Upon leaving the CRF and FHF, the Cans and the casks are weighed and sealed. In the case of the casks and the in-Can makeup fuel tanks, the outgoing fissile and fertile composition has been carefully determined by isotope. Upon arrival at the plant, these containers are reweighed and the seals checked in the presence of IAEA inspectors. The outgoing Cans and fuelsalt

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[1] Noble gases are bubbled off, cooled, and stored in high pressure bottles for return to the recycling center, However, this system too is located below the silo hall deck. And even if it were not, there is no way, it could be used to extract fissile material.

casks are also weighed and sealed, and then reweighed upon arrival at the recycling facility. At the recycling facilities, the isotopic composition of the returned material for each PMOD is determined, and compared with the outgoing composition and the PMOD's power output.[2]

3 The Proliferant Nation Threat

3.1 The Uranium Bomb Route

If a ThorCon host nation decides to use ThorCon fuelsalt to build a bomb, he has two basic paths:

1. a uranium bomb, or
2. a plutonium bomb.

We must assume that a rogue host nation will be able to separate the uranium from the rest of the fuelsalt by fluorine volatility. However, a uranium bomb requires highly enriched uranium. ThorCon is a DMSR (Denatured Molten Salt Reactor).

Table 1 shows the ThorCon fuel is always denatured. *Denatured* just means that the uranium must undergo a lot of enrichment before it becomes usable in a weapon. The column labeled "fissile mult fract" is 7.33 times the ^{233}U fraction plus 4 times the ^{235}U fraction. To be legally denatured, this weighted fraction must be less than the ^{238}U fraction. The column labeled "denatured ratio" is this weighted fraction divided by the ^{238}U fraction. A ratio less than 1.0 means the fuel is over-denatured. Roughly speaking, 1 minus the ratio is the fraction of ^{238}U that you could remove and still be denatured. The ThorCon baseline fuel starts out just denatured, but becomes progressively more over-denatured thereafter. To use ThorCon fuel in a bomb, the host nation will require a full scale enrichment facility.

Moreover, the bombmaker will have to deal with some ^{232}U. In the process of transmuting thorium to ^{233}U, some ^{232}U is created. The ^{232}U decay chain includes a series of gammas including a nasty 2.6 MeV gamma. As Figure 3 shows the ^{232}U concentration starts out at zero and rises slowly to about 22 ppm at year 8. This will seriously complicate a bomb maker's life and make any transgressions easily trackable.[3] 20 ppm may force him to run his centrifuges in a hot cell. And the enrichment process will enrich ^{232}U more effectively than ^{235}U. Given the choice, a bombmaker would much rather have ^{232}U free material, even if it were at a lower enrichment.

If a proliferant nation were to use ThorCon fuel to make a uranium bomb, his best move is to divert the fresh fuel. But not only would this be easily detected but it also means that he

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[2] The material balance will be complete except for a small amount of material left in the primary loop, fuelsalt drain tank, and fuelsalt transfer piping after flushing. And this minute heel should level off after the first flushing.

[3] Consider the problems currently facing DOE in disposing of ^{233}U contaminated with 9 to 160 ppm ^{232}U. To transport 3.5 inch diameter cannisters, they intend to use a 30 inch diameter cask with an 11 inch thick annulus of poured lead. The casks have to be loaded remotely. The DOE figures that direct contact with the cannisters would result in a dose rate ranging from 0.01 to 3 Sv/h. The LD50 dose in this period is about 3 Sv.

Table 1: Denatured ratio. Ratio less than 1 means fuel is over-denatured

2015-10-31 2nd test of serp2 2015-11-03T12:29:29

Burn step	days	years	U-232 at. frac.	U-233 at. frac.	U-235 at. frac.	U-238 at. frac	fissile wt frac	denatured ratio
1	0	0.00	0.0000e+00	0.0000e+00	1.9800e-01	8.0200e-01	7.9200e-01	9.8753e-01
2	2	0.01	9.7247e-12	5.4780e-06	1.9768e-01	8.0224e-01	7.9076e-01	9.8570e-01
3	6	0.02	3.5652e-10	4.7603e-05	1.9702e-01	8.0271e-01	7.8842e-01	9.8219e-01
4	14	0.04	3.5290e-09	2.3810e-04	1.9568e-01	8.0356e-01	7.8447e-01	9.7624e-01
5	30	0.08	2.0384e-08	9.4309e-04	1.9297e-01	8.0499e-01	7.7880e-01	9.6746e-01
6	60	0.16	8.7697e-08	2.9543e-03	1.8792e-01	8.0698e-01	7.7332e-01	9.5830e-01
7	120	0.33	3.5071e-07	7.8614e-03	1.7826e-01	8.0972e-01	7.7065e-01	9.5175e-01
8	240	0.66	1.2803e-06	1.7142e-02	1.6131e-01	8.1376e-01	7.7090e-01	9.4732e-01
9	365	1.00	2.6211e-06	2.4694e-02	1.4722e-01	8.1715e-01	7.6987e-01	9.4214e-01
10	730	2.00	7.2498e-06	3.6848e-02	1.2056e-01	8.2510e-01	7.5234e-01	9.1182e-01
11	1095	3.00	1.1857e-05	4.2847e-02	1.0302e-01	8.3188e-01	7.2615e-01	8.7290e-01
12	1460	4.00	1.5467e-05	4.3889e-02	9.4428e-02	8.3668e-01	6.9942e-01	8.3594e-01
13	1825	5.00	1.8131e-05	4.3065e-02	8.9239e-02	8.4085e-01	6.7262e-01	7.9993e-01
14	2190	6.00	1.9929e-05	4.1246e-02	8.6307e-02	8.4442e-01	6.4756e-01	7.6688e-01
15	2555	7.00	2.1111e-05	3.9041e-02	8.4374e-02	8.4772e-01	6.2367e-01	7.3570e-01
16	2920	8.00	2.1704e-05	3.6606e-02	8.3464e-02	8.5056e-01	6.0218e-01	7.0798e-01

loses the power this fuel would generate.

In short, ThorCon's always meets the denatured requirement. To make a uranium bomb, the proliferant nation would require a full scale enrichment facility. And unless he diverts the fuel on arrival, he would face the additional problems of enriching fuel contaminated with ^{232}U.

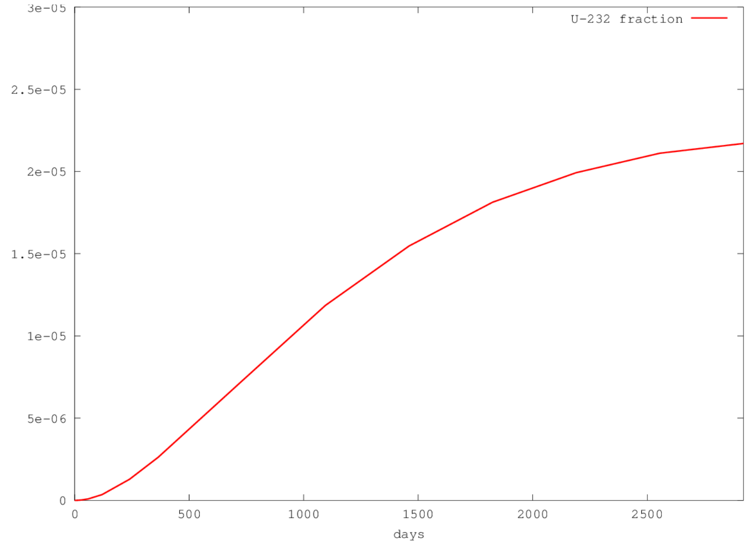

Figure 3: ^{232}U concentration

3.2 The Plutonium Bomb Route

3.2.1 Production and Removal of Weapons Grade Plutonium

The other pathway for a proliferant nation is a plutonium bomb. One of the major problems facing a country that wants a reliable, high yield plutonium bomb is preventing premature detonation due to spontaneous fission in the fissile material. For LWR the main source of this spontaneous fission is ^{240}Pu. This is the reason plutonium is divided into three grades per Table 2.

Table 2: Plutonium Grades

Weapons Grade	$<7\%$ ^{240}Pu
Fuel Grade	7 to 19% ^{240}Pu
Reactor Grade	$>19\%$ ^{240}Pu

A reliable, high yield weapon requires Weapons Grade plutonium. Plutonium enrichment is currently infeasible. Therefore Weapons Grade plutonium is usually produced in special purpose reactors that are designed to make it easy to extract the right isotopic mixture, preferably 90% or more ^{239}Pu and less than 7% ^{240}Pu. To obtain this quality, it is necessary to remove the fuel after an irradiation period of around 60 days. After this time the fraction of ^{239}Pu starts to fall and the fraction of unwanted plutonium isotopes, mainly ^{238}Pu and ^{240}Pu starts to rise. ^{238}Pu and ^{240}Pu both have high spontaneous fission rates which in a bomb can trigger pre-detonation and a drastic drop in yield. On top of this, ^{238}Pu, a prolific alpha emitter, puts out heat at about 570 W/kg. It is is the preferred source of power for deep space probes. The weapons designer must figure out a way of dissipating this heat. This is not easy since a plutonium bomb must be wrapped in a tight, carefully machined, blanket of explosives.

One problem with starting out with fresh salt every 8 years is ThorCon will produce Weapons Grade plutonium at the beginning of each such period. This is true of any reactor which burns low enriched uranium. This was demonstrated by the Iranians in October, 2012 when they shut down the Bushehr pressurized water reactor after only 60 days operation, and pulled the fuel elements.[3] The removal period was said to be Oct 22 to 29. WSJ received estimates of 10 to 100 kg of Weapons Grade plutonium in these fuel elements.[4] After a long silence, the shutdown was blamed on “stray bolts” that had fallen to the bottom of the reactor vessel. The dropped bolts story was later denied by the Russians who said the shutdown was for “safety testing”. Others claimed it had to do with the handover from the Russians to the Iranians.

The US and others protested, but did nothing. The assumption presumably was that the Iranians do not have the capability of separating the plutonium from the fission products. Maybe,

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[4] Fission of a gram of ^{235}U produces about a megawatt-day(MWD) of thermal energy. An LWR with a Pu conversion ratio of 0.6 will produce 0.6 grams per MWD. Bushehr operating at 3000 MW(th) would produce about 108 kg of Pu in 60 days. Presumably, Bushehr was not always at full power during this period.

but we can be confident they have a supply of Weapons Grade Pu waiting for the day they do. In mid-2013, the Bushehr reactor resumed operation.

Table 3: ThorCon Plutonium composition as a function of burnup

2015-10-31 2nd test of serp2 2015-11-07T21:50:00

Burn step	days	years	Pu-238 kg	Pu-239 kg	Pu-240	Pu-242 kg	Total Pu kg	Pu-238 wt frac	Pu-239 wt frac	Pu-240 wt frac	Pu-242 wt frac
1	0	0.00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2	2	0.01	5.42e-10	6.55e-02	1.48e-04	1.41e-10	6.56e-02	8.26e-09	9.98e-01	2.26e-03	2.14e-09
3	6	0.02	3.28e-08	4.31e-01	2.36e-03	1.97e-08	4.33e-01	7.56e-08	9.95e-01	5.44e-03	4.55e-08
4	14	0.04	8.57e-07	1.43e+00	1.80e-02	8.61e-07	1.45e+00	5.92e-07	9.87e-01	1.25e-02	5.95e-07
5	30	0.08	1.48e-05	3.46e+00	9.61e-02	2.25e-05	3.56e+00	4.17e-06	9.72e-01	2.70e-02	6.33e-06
6	60	0.16	1.70e-04	6.89e+00	3.87e-01	3.81e-04	7.30e+00	2.33e-05	9.44e-01	5.30e-02	5.23e-05
7	120	0.33	1.64e-03	1.25e+01	1.37e+00	5.57e-03	1.40e+01	1.17e-04	8.90e-01	9.79e-02	3.97e-04
8	240	0.66	1.37e-02	2.02e+01	4.12e+00	6.65e-02	2.54e+01	5.40e-04	7.97e-01	1.62e-01	2.62e-03
9	365	1.00	4.66e-02	2.55e+01	7.16e+00	2.57e-01	3.53e+01	1.32e-03	7.22e-01	2.03e-01	7.28e-03
10	730	2.00	3.25e-01	3.56e+01	1.45e+01	1.79e+00	5.99e+01	5.42e-03	5.94e-01	2.42e-01	2.99e-02
11	1095	3.00	9.37e-01	4.30e+01	1.95e+01	4.43e+00	8.06e+01	1.16e-02	5.34e-01	2.42e-01	5.50e-02
12	1460	4.00	1.92e+00	5.04e+01	2.33e+01	7.69e+00	1.00e+02	1.91e-02	5.03e-01	2.33e-01	7.67e-02
13	1825	5.00	3.22e+00	5.84e+01	2.66e+01	1.12e+01	1.20e+02	2.69e-02	4.86e-01	2.22e-01	9.31e-02
14	2190	6.00	4.82e+00	6.71e+01	2.97e+01	1.47e+01	1.41e+02	3.43e-02	4.77e-01	2.11e-01	1.05e-01
15	2555	7.00	6.69e+00	7.60e+01	3.27e+01	1.82e+01	1.61e+02	4.15e-02	4.71e-01	2.03e-01	1.13e-01
16	2920	8.00	8.78e+00	8.56e+01	3.57e+01	2.15e+01	1.83e+02	4.80e-02	4.68e-01	1.95e-01	1.18e-01

Table 3 shows that at 60 days into the fuel cycle, a 250 MWe ThorCon module will have produced 7 kg of 94% pure ^{239}Pu.[5] After 120 days, the material is no longer weapons grade. ThorCon's Pu quality deteriorates more rapidly with burn up than in a LWR, primarily due to the growth in ^{238}Pu. ThorCon produces roughly 5 times as much ^{238}Pu as a LWR.

At first glance it would seem easier to remove the fuel from a liquid fuel reactor than a solid fuel LWR. But as discussed in Section 2.1, ThorCon is designed to

1. make the removal of fuel from a PMOD a difficult task requiring at a minimum an extended shut down, opening large hatches on the surface, and multiple multi-100 ton lifts;
2. ensure that the attempt would be revealed by even the most rudimentary surveillance system,

And while removing fuel from a LWR is a technically difficult problem, solid fuel reactor designers have gone to great lengths to turn this into a routine operation. The resulting refueling systems are both ingenious and very expensive. They drive the whole design. But they do work as the Iranians demonstrated. See page 9. It turns out that the refueling system makes the removal of WG plutonium from a LWR easier than the removal from a ThorCon which does no on-site refueling.

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[5] A one GWe ThorCon produces ^{239}Pu at about 1/4th the rate that a 1 GWe light water NPP does. This is mainly due to neutrons being absorbed in thorium rather than U-238. But the better thermal efficiency helps as well.

3.2.2 The Separation Problem

With respect to production and removal of weapons grade plutonium, there is not all that much difference between a LWR and ThorCon. Both require an easily observable, early shut down and a difficult but not impossible removal step to obtain Weapons Grade plutonium. Both will then require a Purex plant to separate the plutonium from the uranium and the fission products. A Purex plant is both technical difficult and an immense investment. Purex plants have been built by only a handful of countries. But as North Korea shows it can be done if a nation is willing to devote a significant portion of its GDP to the project.

But even if a country that has somehow diverted ThorCon WG plutonium is able and willing to build a Purex plant, she faces yet another nearly insurmountable hurdle: thorium. Each 10 kg of ^{239}Pu will be dissolved in 50 tons of highly radioactive salt including about 10 tons of thorium. Unless essentially all this thorium is separated from the plutonium, the material will be useless as a bomb. A 10:1 mixture of thorium to plutonium won't even sustain a chain reaction, no matter how much of it she has.[2][Figure 7]

Standard Purex does a poor job of separating plutonium and thorium. The rogue country will require a Thorex plant. Like Purex, Thorex is a solvent-solvent extraction process. But Thorex is much tougher than Purex due to the insolubility of thorium, which requires highly corrosive hydrogen fluoride and results in long dissolution times, and the inability to change thorium's oxidation state. Thorex is so difficult it has never been implemented on an industrial scale.[1][Ch. 7] As far as we know, all but one of the Thorex efforts were abandoned by 1970. The exception is India; but the Indian flowsheet does not attempt to produce thorium-free plutonium.[1][page 84]

Thorium not only makes ThorCon much more resistant to proliferation via the plutonium bomb path than a Light Water Reactor; it makes it so difficult that it is hard to imagine a situation in which a country would attempt this route.

4 Theft of Fuelsalt by a Sub-national Group

Another possible threat is theft of ThorCon fuelsalt by a terrorist group. Section 2.1 argues that undetected theft will be extremely difficult. But suppose it happens anyway. In such a situation, the standard assumption within the proliferation community is that any yield which exceeds a conventional chemical explosion is a *nuclear threat*. See, for example, Bathke et al.[2] To be conservative, both heat load and spontaneous fission are deemed not to be significant problems in achieving such modest yields. However, at the same time the sub-national group is assumed to have no enrichment or reprocessing facilities.

Bathke et al suggest diluting the plutonium with thorium. If sufficient thorium is mixed with the plutonium, it will absorb enough neutrons to prevent criticality. According to their Figure of Merit, a Pu + Th mixture in which the thorium concentration is greater than two thirds is *Unattractive* material even for a group that is satisfied with a very low yield. A mixture which is more than 90% thorium has a Bathke *attractiveness* of zero.[2][Figure 7] It is useless even for a very low yield fizzle device.

ThorCon follows this advice. Table 4 shows the total amount of uranium, plutonium and thorium in the the fuelsalt as a function of burnup.[6] Even at the end of the cycle, the ratio of thorium to all plutonium is over 50. At the critical part of the cycle, when the reactor is producing weapons grade plutonium, the ratio of thorium to plutonium is over 1000.

ThorCon fuel is at least as hard to steal as that in a LWR. Moreover, if the fuelsalt were stolen, it would be worthless to the most undiscerning thieves unless they could separate the plutonium from the thorium. This would require a Thorex separation facility an extremely difficult, if not impossible, proposition for any sub-national group.[1][page 81]

If you accept the Bathke et al position, ThorCon is far more resistant against sub-national group theft than a LWR which requires only the removal of uranium.

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[6] For Bathke et al, uranium is also an effective dilutant; but it is hard to imagine an outfit that can make even a weak fizzle device out of extremely low grade plutonium but is unable to remove the uranium by fluorine volatility. Separating the thorium and plutonium is far more difficult.

Table 4: ThorCon uranium, plutonium and thorium content as a function of burnup

2015-10-31 2nd test of serp2 2015-11-07T21:50:00

Burn step	days	years	U-233 kg	U-235 kg	Total U	Pu-238 kg	Pu-239 kg	Pu-240 kg	Total Pu kg	Th-232 kg
1	0	0.00	0.000e+00	6.488e+02	3.311e+03	0.000e+00	0.000e+00	0.000e+00	0.000e+00	1.441e+04
2	2	0.01	1.804e-02	6.567e+02	3.356e+03	5.423e-10	6.547e-02	1.485e-04	6.562e-02	1.437e+04
3	6	0.02	1.584e-01	6.612e+02	3.391e+03	3.276e-08	4.309e-01	2.358e-03	4.333e-01	1.433e+04
4	14	0.04	8.031e-01	6.657e+02	3.437e+03	8.568e-07	1.428e+00	1.801e-02	1.446e+00	1.428e+04
5	30	0.08	3.214e+00	6.634e+02	3.473e+03	1.484e-05	3.457e+00	9.606e-02	3.556e+00	1.424e+04
6	60	0.16	1.019e+01	6.536e+02	3.514e+03	1.699e-04	6.886e+00	3.869e-01	7.297e+00	1.419e+04
7	120	0.33	2.761e+01	6.315e+02	3.579e+03	1.638e-03	1.248e+01	1.374e+00	1.403e+01	1.412e+04
8	240	0.66	6.222e+01	5.905e+02	3.699e+03	1.370e-02	2.023e+01	4.124e+00	2.539e+01	1.399e+04
9	365	1.00	9.366e+01	5.631e+02	3.865e+03	4.655e-02	2.551e+01	7.158e+00	3.533e+01	1.382e+04
10	730	2.00	1.626e+02	5.366e+02	4.497e+03	3.247e-01	3.559e+01	1.452e+01	5.995e+01	1.318e+04
11	1095	3.00	2.084e+02	5.053e+02	4.956e+03	9.369e-01	4.299e+01	1.950e+01	8.057e+01	1.271e+04
12	1460	4.00	2.401e+02	5.211e+02	5.576e+03	1.917e+00	5.044e+01	2.335e+01	1.003e+02	1.208e+04
13	1825	5.00	2.624e+02	5.483e+02	6.209e+03	3.224e+00	5.836e+01	2.661e+01	1.201e+02	1.144e+04
14	2190	6.00	2.781e+02	5.869e+02	6.872e+03	4.824e+00	6.706e+01	2.966e+01	1.405e+02	1.077e+04
15	2555	7.00	2.888e+02	6.296e+02	7.541e+03	6.687e+00	7.597e+01	3.270e+01	1.613e+02	1.009e+04
16	2920	8.00	2.960e+02	6.807e+02	8.242e+03	8.784e+00	8.560e+01	3.572e+01	1.830e+02	9.381e+03

5 Security

A related concern is capture of the plant, perhaps with inside help, by a nihilist group with the intent of “blowing it up”. The motives might be retribution, revolution, jihad, or blackmail. But the goal is to cause — or credibly threaten — a large release of radioactive material.

Due to the totally passive nature of the shutdown and cooling process, capture of a ThorCon control room gains the attackers almost nothing. They can generate a Loss of Flow or Loss of Heat Sink by shutting down the primary loop pump or the downstream pumps. But all that will do is shut down the plant and worst case force a drain.[4][Section 2] They could run the power output up and down causing problems for the grid, but this could be accomplished more easily and far more permanently by attacking the grid itself.

A key here is protecting the silo coldwall loop. The silo coldwall piping is not accessible. It is in the silo hall basement or buried between the silo hall and the pond. Assuming total control, the attackers could breach the pond condenser, but that will not stop the decay heat cooling process. It just adds the pond water to the loop.

If they had extended total control they could force a Both Paths Lost casualty by cutting the normal decay heat path to the turbogenerator condensers and then blanking off both sides of the coldwall loop at the pond condensers. However, even if they were able to do this, the basement water would provide 269 days of decay heat cooling.[4][Section 3.5] Military response units would have over 8 months to root them out.

Control of the crane will be important to the attackers. It’s the only way to lift out the hatch covers which are 50 to 300 ton plugs. The crane will be protected from unauthorized use by keys, alarms, and interlocks. If the attackers are able to break through this protection, the counter is to disable the crane. Unlike the rest of the ThorCon fission island, the crane is a soft target, easily disabled with artillery or an air strike.[7]

Without the crane, it is still possible to gain access to a PMOD’s silo hall. On the forward bulkhead of the silo hall, there is access just large enough for a man via an air lock. Assuming extended total control, a terrorist group could force open this entry, and put explosives on the silo hall working deck. However, that is as far as they can get. The explosion on the working deck would still be nearly five meters from the top of the Can, and 15 meters from the top of the drained fuelsalt. The Can would still be protected by the silo hall deck, nearly 3 m of water, the lead gamma shield, the radtank bottom, and the Can lid. It would take a large bomb to have a chance of penetrating all these barriers. And this bomb would also have to take out the silo hall roof in order to have an unobstructed release.

Finally, if the terrorists were somehow able to penetrate all the barriers, the release would be largely limited to the inventory of volatile fission products. The already existing cesium and strontium is chemically bound to the fuelsalt. By far the most important volatile fission product

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[7] One of the responsibilities of the plant security force will be to disable the crane if they become concerned about being overrun.

is ^{137}Xe which decays to ^{137}Cs. Module full power ^{137}Xe inventory is 0.062 grams. Fukushima released 4 kg of ^{137}Cs, 64,000 times as much.

The actual release of ^{137}Xe will depend on how rapidly the attackers are able to obtain control of the plant and then blast through:

1. The 3 m thick double skinned silo hall roof. Each skin is 25 mm thick.
2. The 50 mm thick silo hall deck.
3. The 3 m deep water filled radtank.
4. The 270 mm thick lead shield,
5. The 25 mm radtank bottom.
6. The 50 mm thick Can lid.

^{137}Xe has a half-life of 3.8 minutes. If it takes the attackers 38 minutes from the time the plant was scrammed to create a path from the primary loop to the outside, the potential release will be down one-thousand-fold to 62 μg.

ThorCon is not a soft target, even for a group that has obtained total control. As a practical matter, there is very little the attackers can do other than shut the plant down, and cause some damage which will be confined to the plant itself.

This implies that the security system can largely rely on response and counter-attack. A modest security force can deter or fend off protests and small, poorly organized attacks; but cannot be expected to repel a determined, well-planned attack from an ISIS-like organization. At that point national or international forces will have to respond and recapture the plant. This strategy is robust against the plant's security force being suborned or otherwise compromised. In this case, the weaker the security force the better.

6 Cyber Attack

ThorCon's release resistance depends on neither operator nor control system action. On any temperature excursion significantly above normal operating temperature, the reactor will shut itself down and passively handle the decay heat. There is nothing a confused operator or a malfunctioning control system can do to prevent the shutdown or the cooling.

This has obvious security implications. The fission island control system has no connection to the outside. But even if a cyber attacker could hack into the control system, since ThorCon's safety is totally passive, it cannot be compromised by fraudulent control signals.

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