"Sapienza" Università degli Studi di Roma
Ingegneria Astronautica, Elettrica ed Energetica
Impianti Elettronucleari

Seminari del Prof. Agostino Mathis – Anno 2022

ENERGIA NUCLEARE
PER LA SOSTENIBILITA’ A LUNGO TERMINE

Secondo Seminario – 10 maggio 2022

1. L’industria nucleare oggi nel mondo
2. Energia nucleare e fabbisogno di energia al 2100
3. Nucleare innovativo: gli Small Modular Reactors
4. Motori nucleari per terra, mare e spazio

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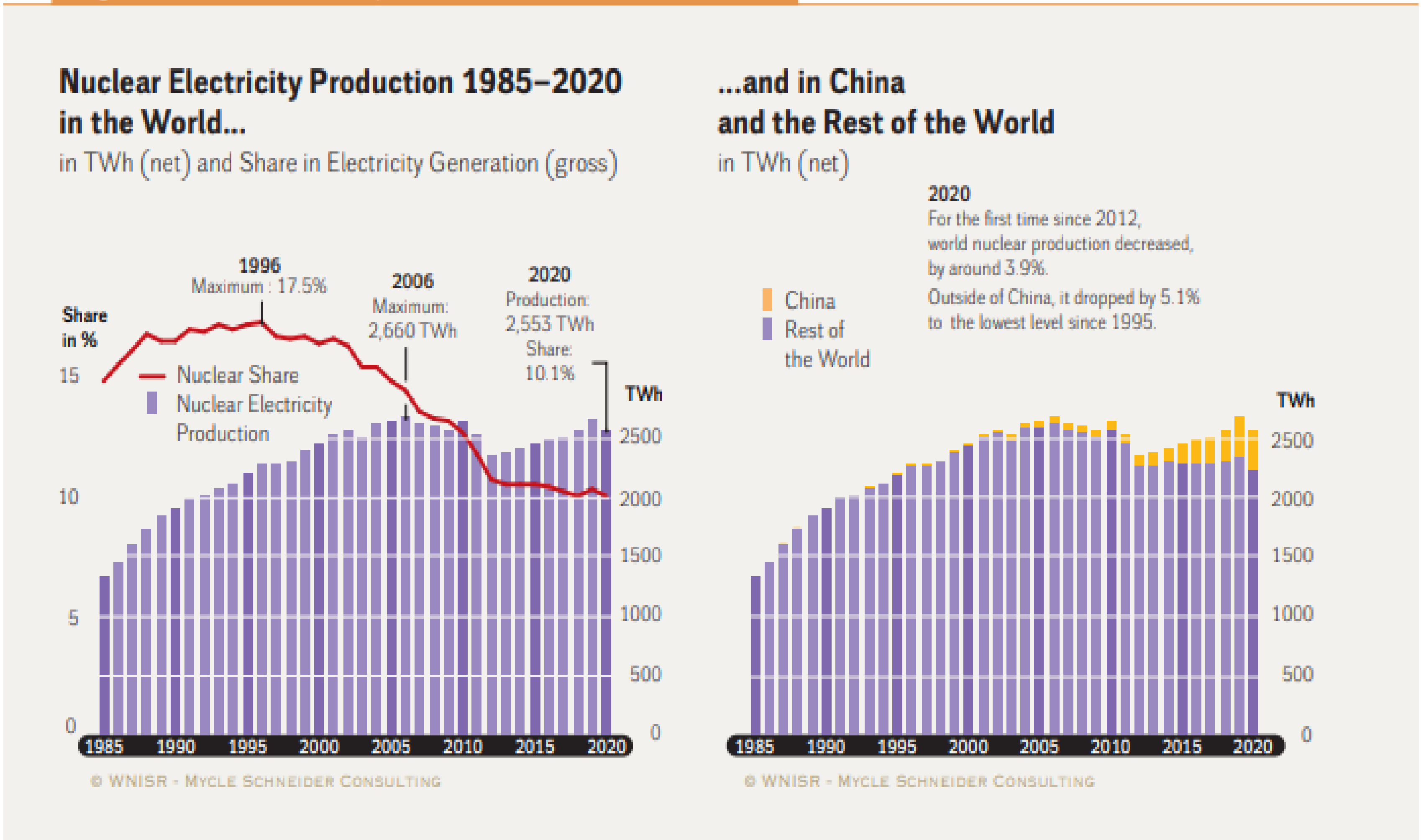
L’industria nucleare oggi nel mondo

L’industria nucleare, almeno nel mondo occidentale, è tuttora in **crisi**, e potrà riprendersi solo con una **profonda transizione** nelle **tecnologie**, nelle **organizzazioni industriali**, nelle **normative** e negli **organi di sicurezza e protezione**, e **soprattutto nelle prassi costruttive ed operative**.

Il recente **”The World Nuclear Industry Status Report 2021”** (*) fornisce un documentato panorama dello stato attuale dell’industria nucleare civile nel mondo: se ne traggono alcune delle tavole seguenti.

(*) https://www.worldnuclearreport.org/IMG/pdf/wnisr2021-hr.pdf ”The World Nuclear Industry - Status Report 2021” A Mycle Schneider Consulting Project - Paris, September 2021.

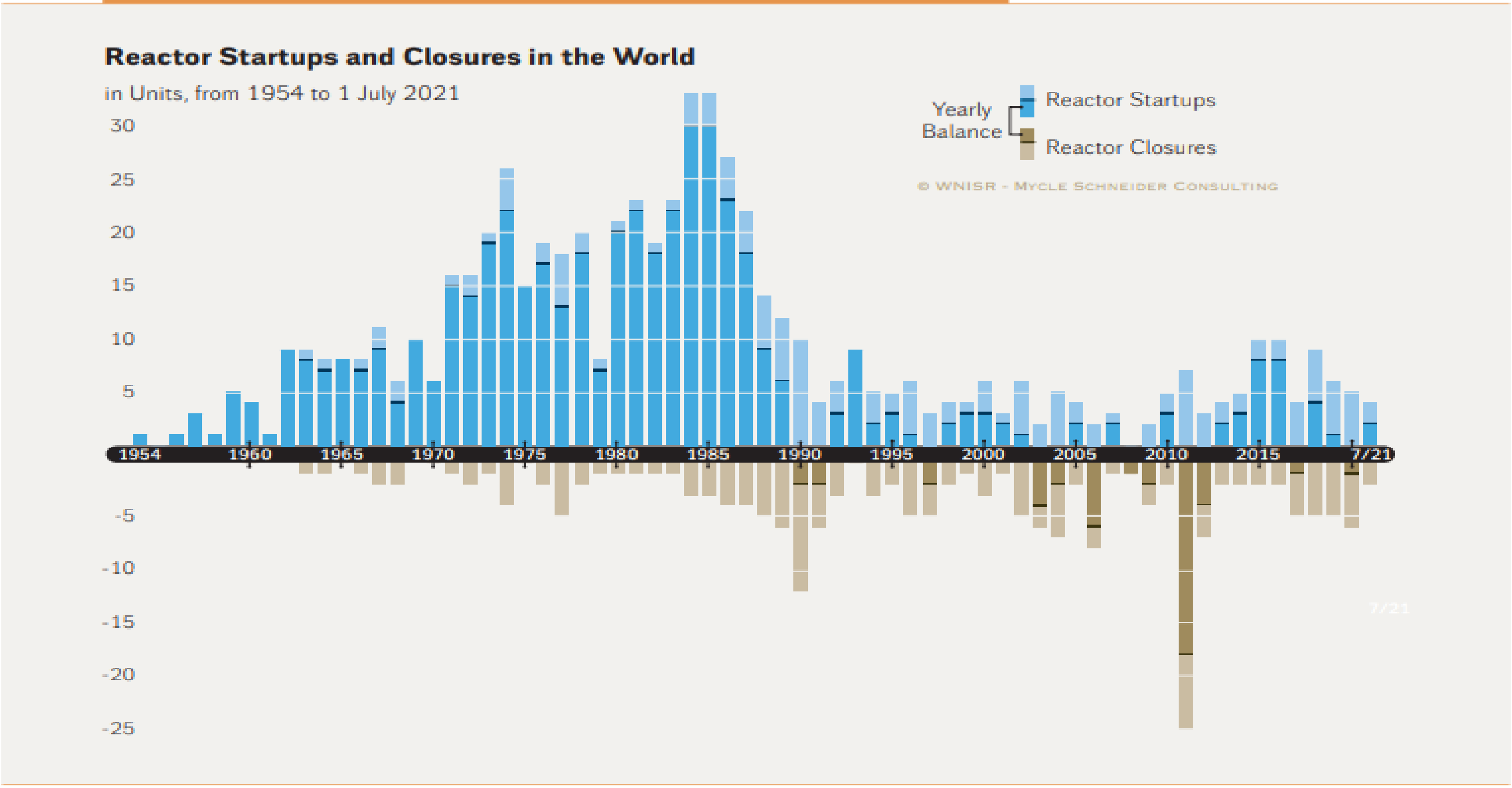
Figure 1 · Nuclear Electricity Generation in the World... and China



Sources: WNISR, with BP, IAEA-PRIS, 2021[17]

From: ”The World Nuclear Industry Status Report 2020” A Mycle Schneider Consulting Project - Paris, September 2021.

Figure 4 · Nuclear Power Reactor Grid Connections and Closures in the World

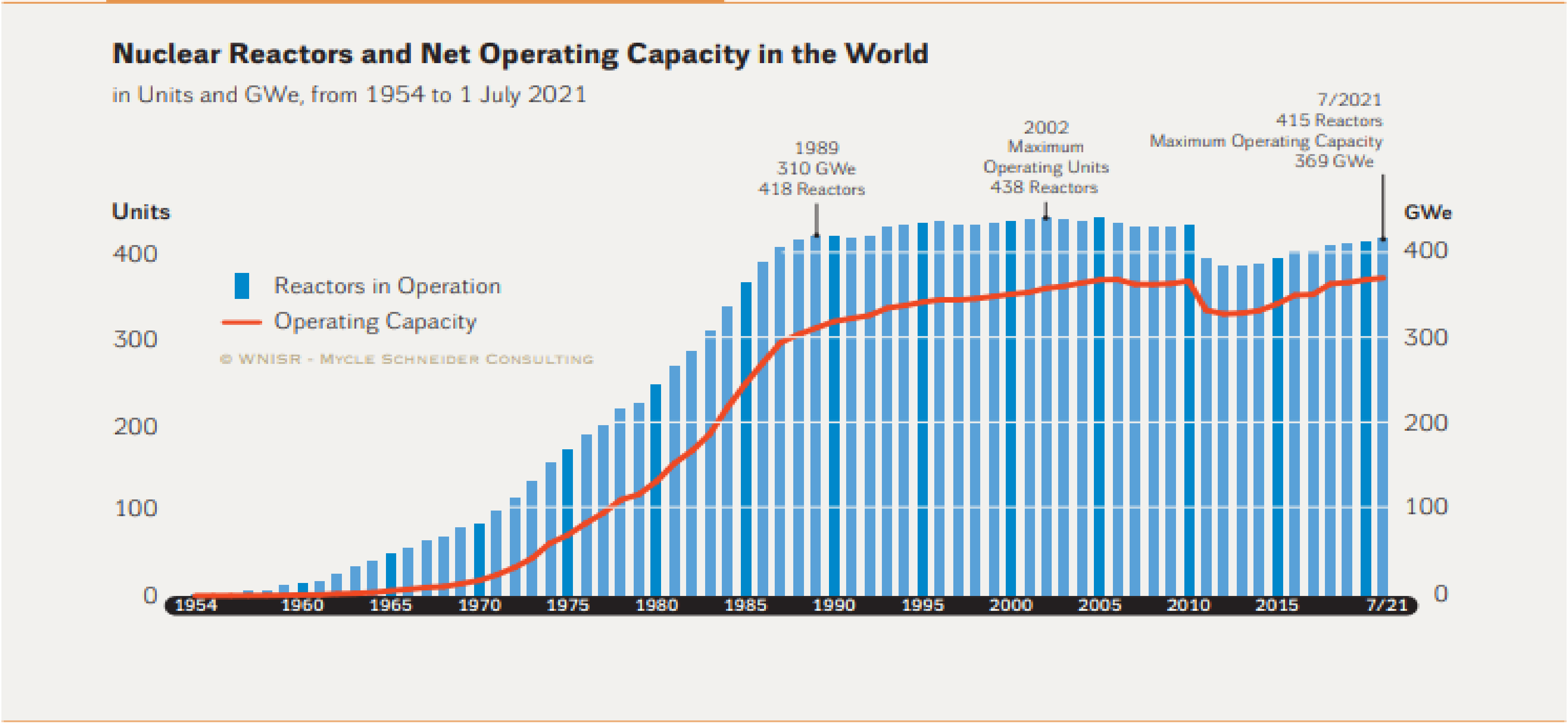


Sources: WNISR, with IAEA-PRIS, 2021

Notes:
As of 2019, WNISR is using the term "Closed" instead of "Permanent Shutdown" for reactors that have ceased power production, as WNISR considers the reactors closed as of the date of their last production. Although this definition is not new, it had not been applied to all reactors or fully reflected in the WNISR database; this applies to known/referenced examples like Superphénix in France, which had not produced in the two years before it was officially closed or the Italian reactors that were de facto closed prior to the referendum in 1987, or some other cases. Those changes obviously affect many of the Figures relating to the world nuclear reactor fleet (Startup and Closures, Evolution of world fleet, age of closed reactors, amongst others.)

From: "The World Nuclear Industry Status Report 2020" A Mycle Schneider Consulting Project - Paris, September 2021.

Figure 6 · World Nuclear Reactor Fleet, 1954–2021

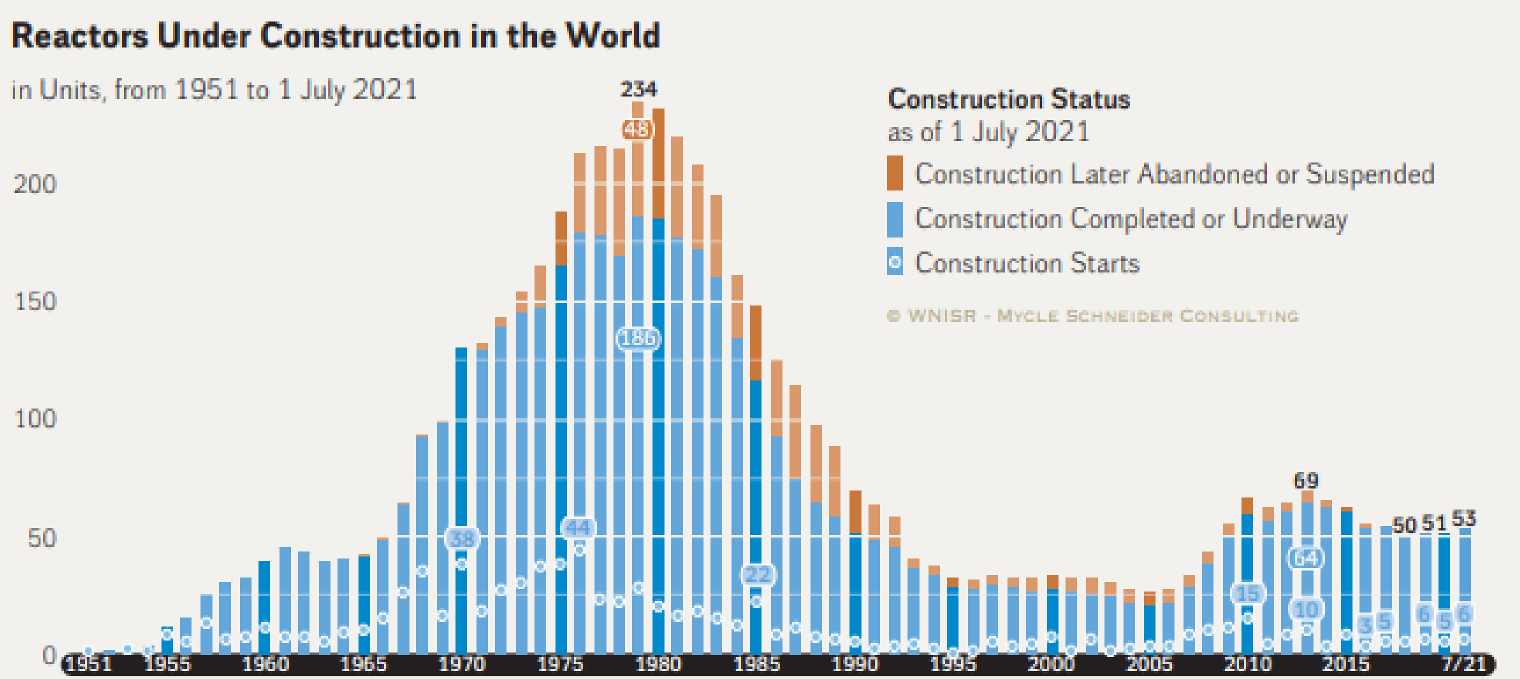


Sources: WNISR, with IAEA-PRIS, 2021

Note
Changes in the database regarding closing dates of reactors or LTO status slightly change the shape of this graph from previous editions. In particular, the previous "maximum operating capacity" of 2006 (overtaken in July 2019) is now at 367 GW.

From:" The World Nuclear Industry Status Report 2020" A Mycle Schneider Consulting Project - Paris, September 2021.

Figure 7 · Nuclear Reactors "Under Construction" in the World (as of 1 July 2021)

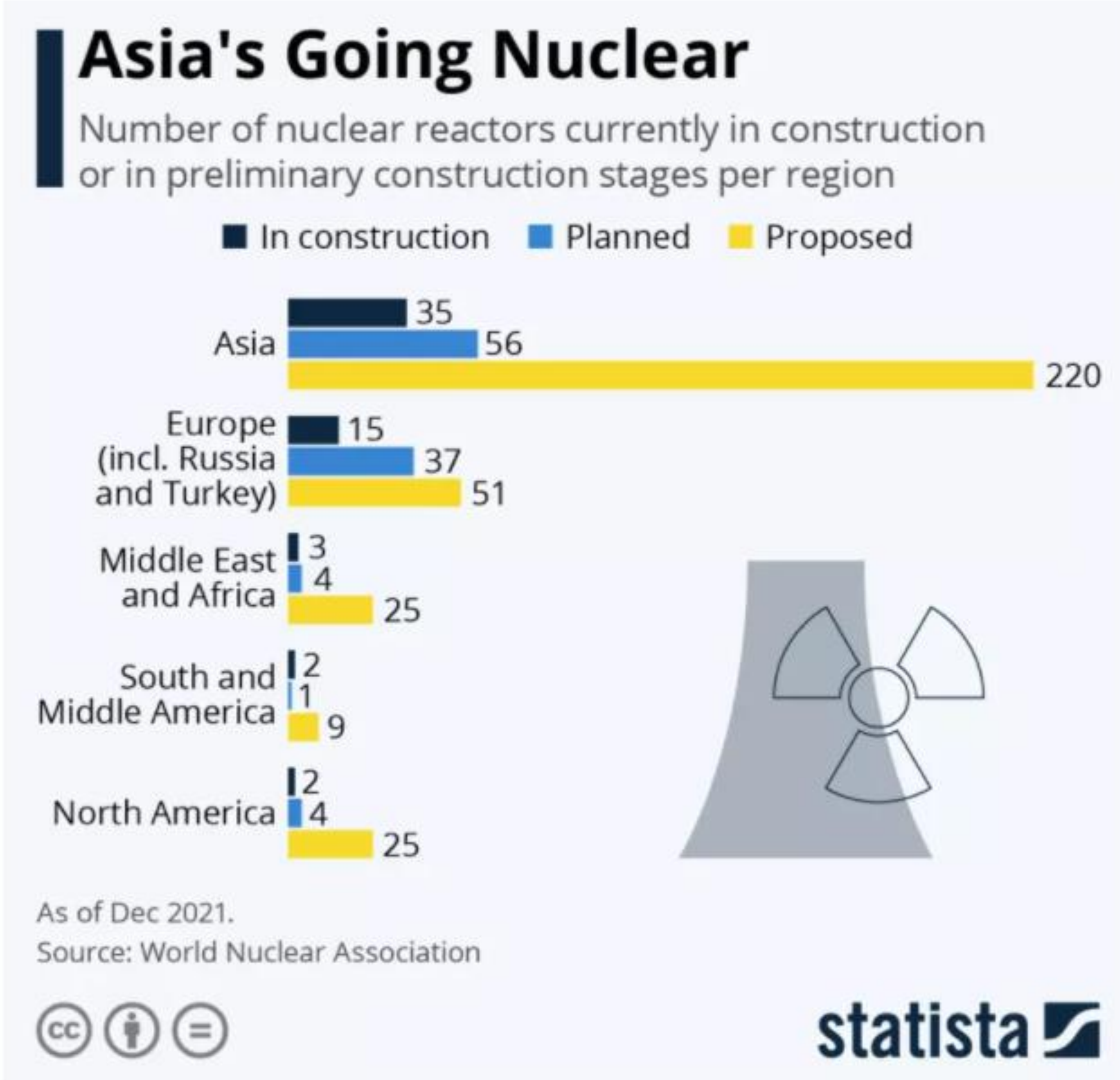


Sources: WNISR, with IAEA-PRIS, 2021

Notes:

This figure includes construction of two CAP1400 reactors at Rongcheng/Shidaowan, although their construction has not been officially announced (see China Focus). At Shidao Bay, the plant under construction since 2012 has actually two reactors on the site and is therefore counted as two units as of WNISR2020.

From: "The World Nuclear Industry Status Report 2020" A Mycle Schneider Consulting Project - Paris, September 2021.



Asia plan to increase their number of nuclear reactors. Image: Statista

From: https://www.weforum.org/agenda/2022/01/asia-nuclear-reactors-power-energy/

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Google Translate

Nuclear Power in China

(Updated February 2022)

- The impetus for nuclear power in China is increasingly due to air pollution from coal-fired plants.
- China's policy is to have a closed nuclear fuel cycle.
- China has become largely self-sufficient in reactor design and construction, as well as other aspects of the fuel cycle, but is making full use of western technology while adapting and improving it.
- Relative to the rest of the world, a major strength is the nuclear supply chain.
- China's policy is to 'go global' with exporting nuclear technology including heavy components in the supply chain.

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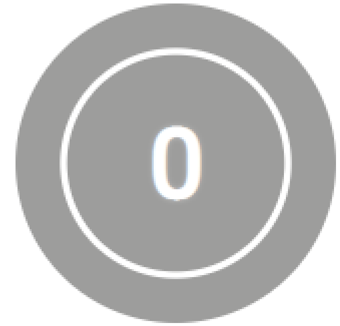
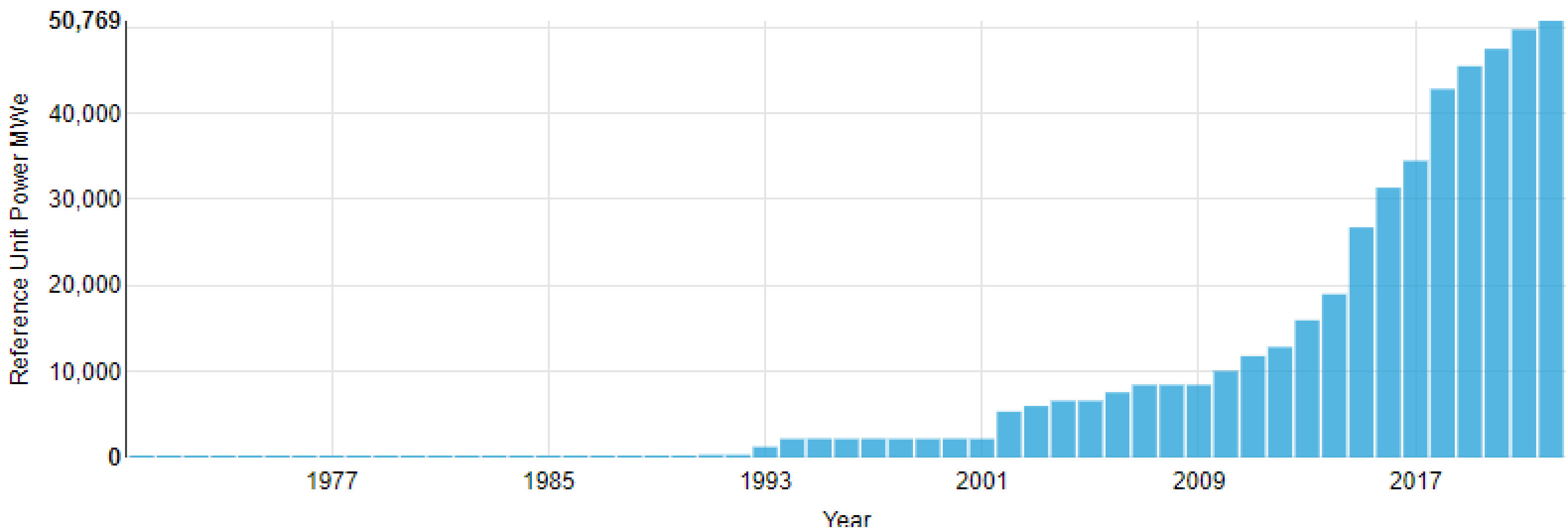
Operable Reactors	Reactors Under Construction	Reactors Shutdown
		
50,769 MWe	19,404 MWe	0 MWe

Operable nuclear power capacity



Green | Energy & Science

China's Climate Goals Hinge on a $440 Billion Nuclear Buildout

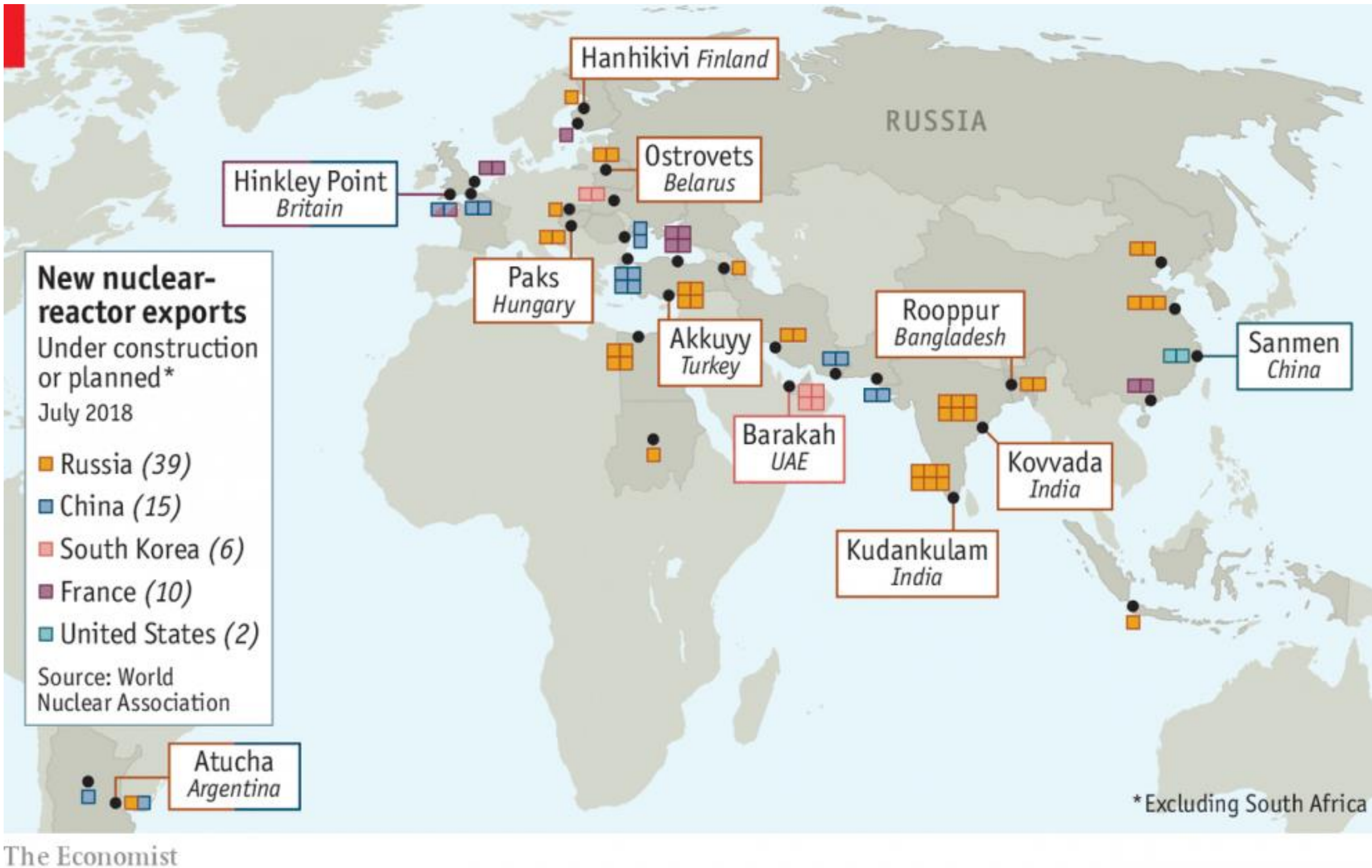
China is planning at least 150 new reactors in the next 15 years, more than the rest of the world has built in the past 35.

By Dan Murtaugh and Krystal Chia

2 novembre 2021, 21:00 CET

Russia leads the world at nuclear-reactor exports

In April 2018 Russia started building Turkey's first nuclear plant, worth $20bn. Its first reactor is due for completion in 2023. Rosatom says it has 33 new plants on its order book, worth some $130 bn. A dozen are under construction, including in Bangladesh, India and Hungary.



From: https://www.economist.com/graphic-detail/2018/08/07/russia-leads-the-world-at-nuclear-reactor-exports

Export sales for Russian nuclear plants

Russia currently has abroad, besides **10 plants operating**, **8 plants in construction, 11 contracted, 7 ordered and up to 30 proposed worldwide**, across **Europe, Southeast Asia, North Africa and the Middle East**.

Russia's policy for building nuclear power plants in non-nuclear weapons states is to deliver on a **turnkey basis**, including **supply of all fuel and repatriation of used fuel for the life of the plant**.

Rusatom Overseas expects two export Russian reactors constructed on a **build-own-operate (BOO) basis** to be operating soon after 2020 and 24 by 2030.

From: http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx

THE CONVERSATION
Academic rigour, journalistic flair

Russia's nuclear power exports: will they stand the strain of the war in Ukraine?

Published: March 6, 2022 8.24am GMT

What if things go wrong

Since the start of the attack on Ukraine, Russia has faced unprecedented international condemnation, sanctions and targeted blows to its economy.

An immediate consequence has been the suspension and possible termination of Rosatom's Hanhikivi project in Finland. In Hungary, another European Union member, Rosatom's Paks II nuclear plant is clearly in jeopardy.

Other international projects will also come under increasing scrutiny.

The biggest threat to the Russian international nuclear power initiative will be to the financing of projects. An already weakened Russian economy hit by foreign sanctions and war costs is not going to be able to afford to offer the massive loans on which all its foreign nuclear projects depend.

Prospettive del NUCLEARE negli USA per il 2022

ELECTRIC POWER | ENERGY TRANSITION — 23 Dec 2021 | 12:00 UTC

Commodities 2022: Nuclear energy advocates see new climate focus buoying industry

HIGHLIGHTS

Infrastructure bill funds two reactors, including one in Wyoming

Legislation includes $6 billion in credits for merchant nuclear units

One new reactor expected to come online in 2022, one to retire

The current focus on climate change has changed the conversation on nuclear energy, creating momentum for public and private sector action **in 2022** to help push advanced nuclear technologies from concept to reality, nuclear advocates have said.

"It has been a huge, huge change," said Jeremy Harrell, managing director of policy at ClearPath. Democratic lawmakers who had been skeptical of nuclear power now see it as a climate imperative, he said. Republicans who supported nuclear energy for economic, emissions, and national security reasons now have partners in Democrats, he said Dec. 15.

At the federal level, the fact that President Joe Biden embraced nuclear energy from the start set a positive tone for the policy environment, said John Kotek, senior vice president of policy development and public affairs at the Nuclear Energy Institute, Dec. 17.

Energia nucleare: quali obiettivi a fine secolo?

Why We Need Innovative Nuclear Power

Our future will depend on finding every possible source of reliable, carbon-free energy

By Nathan Myhrvold on November 7, 2018

https://blogs.scientificamerican.com/observations/why-we-need-innovative-nuclear-power/

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In 2006, Bill Gates and I took a hard look together at all the options humanity has for powering the 21st century. At that time, **81 percent of the world's primary energy—the raw form, before it is converted to electricity, gasoline, etc.—came from fossil fuels.**

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Solar and wind power and biofuels were growing fast, and that was great. But I could already see **major limitations** looming ahead: the huge amounts of land needed, the lack of scalable ways to match their inconstant power to society's unremitting thirst for energy. Anyway, plenty of good minds were already working on improving those kinds of renewable energy.

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It seemed worth a shot. So with the backing of Bill and a few other bold investors, we launched **TerraPower** and dove in to the hard work of trying to make this real.

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On the bright side, TerraPower and a number of other nuclear startups have thrived and are well on their way toward building first-of-a-kind reactors. A 2015 report by Third Way, a think tank, identified **nearly 50 companies and organizations working on advanced reactor projects**. This momentum has drawn a large influx of young engineering talent into the field.

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Meanwhile, global warming lurches ahead. Greenhouse gas emissions continue to grow. So do solar and wind power. **But do you know how much of the world's energy comes from fossil fuels today? It's 81 percent—the same as in 2006.**

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The amount of energy consumed by an **average person in China** (averaged over the year) has jumped by a quarter since 2006, to **three kilowatts (kW)**. That's six times as much as the energy use of an **average African**, which is a **mere 0.5 kW**. But it's still less than a third as much as the **American average**, which at **9.2 kW** is equivalent to nine toasters, running 24/7.

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If I'm right, then humanity's energy challenge is far larger than most people understand. Raising **the global average energy use from 2.4 kW, where it stood in 2017, to the current U.S. level of 9.2 kW per capita** means nearly ***quadrupling* energy production**. And if all that new energy isn't made with near-zero carbon emissions, the climate will be a wreck.

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The challenge is probably even greater than this. Humanity is now around 7.5 billion people. **The U.N. Population Division forecasts that our species will number 10 to 13 billion by century's end**. Ten billion of us using energy at current U.S. rates works out to a **fivefold increase** (*) in global energy production over what we make today. Ironically, one of the strongest factors in reducing population growth rates is prosperity, which is highly correlated with energy use.

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As you read this, for example, millions of computers are humming along in vast data farms built by **Facebook, Amazon, Google, and Microsoft** just waiting for you or someone else to access them over the internet. A generation ago, nobody would have forecast server centers as major energy users. But today **Google consumes as much energy as all of San Francisco**, and energy consumption by data centers in Virginia is huge and **growing at 18 percent a year**.

(*) dagli attuali 20 TW a circa 100 TW!

1 Jun 2018 | 15:00 GMT

TerraPower's Nuclear Reactor Could Power the 21st Century

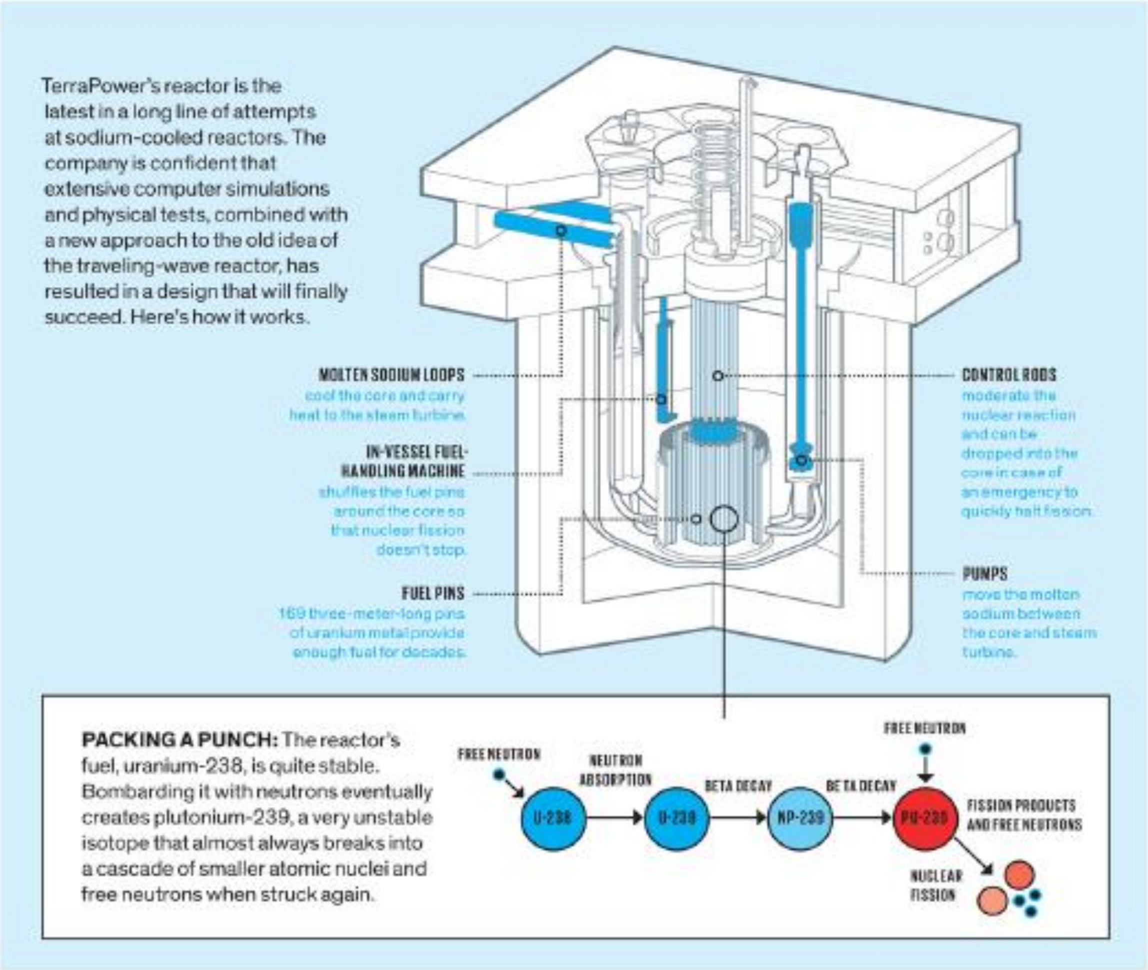
The traveling-wave reactor and other advanced reactor designs could solve our fossil fuel dependency

By **Michael Koziol**

The TerraPower reactor is a new variation on a design that was conceived some 60 years ago by a now-forgotten Russian physicist, Saveli Feinberg. Following World War II, as the United States and the Soviet Union stockpiled nuclear weapons, some thinkers were wondering if atomic energy could be something other than a weapon of war. In 1958, during the Second International Conference on Peaceful Uses of Atomic Energy, held in Geneva, Feinberg suggested that it would be possible to construct a reactor that produced its own fuel.

From: https://spectrum.ieee.org/energy/nuclear/terrapowers-nuclear-reactor-could-power-the-21st-century

The breed-and-burn concept languished until Edward Teller, the driving force behind the hydrogen bomb, and astrophysicist Lowell Wood revived it in the 1990s. In 2006, Wood became an adviser to Intellectual Ventures, the intellectual property and investment firm that is TerraPower's parent company. At the time, Intellectual Ventures was exploring everything—fission, fusion, renewables—as potential solutions to cutting carbon. So Wood suggested the traveling-wave reactor (TWR), a subtype of the breed-and-burn reactor design. "I expected to find something wrong with it in a few months and then focus on renewables," says John Gilleland, the chief technical officer of TerraPower. "But I couldn't find anything wrong with it."



From: https://spectrum.ieee.org/energy/nuclear/terrapowers-nuclear-reactor-could-power-the-21st-century

From: https://en.wikipedia.org/wiki/Traveling_wave_reactor

Traveling wave vs. standing wave[edit]

The **breed-burn wave** in TerraPower's TWR design does not move from one end of the reactor to the other[22] but gradually **from the center out**. Moreover, as the fuel's composition changes through nuclear transmutation, **fuel rods are continually reshuffled** within the core to optimize the neutron flux and fuel usage over time. Thus, instead of letting the wave propagate through the fuel, the fuel itself is moved through a **largely stationary burn wave**. This is contrary to many media reports,[23] which have popularized the concept as a candle-like reactor with a burn region that moves down a stick of fuel. By replacing a static core configuration with an actively managed "standing wave" or "soliton", however, TerraPower's design **avoids the problem of cooling a moving burn region**. Under this scenario, the reconfiguration of fuel rods is accomplished remotely by robotic devices; **the containment vessel remains closed during the procedure**, with no associated downtime.

From:
https://www.engineering.com/DesignerEdge/DesignerEdgeArticles/ArticleID/19610/Bill-Gates-Nuclear-Reactor-Hits-a-Roadblock.aspx

One major problem with a TWR power plant is the price. **It will cost about $3 billion to build a demonstration reactor.** Even Bill Gates isn't rich enough to fund it himself. TerraPower had signed a promising agreement with China to build a demonstration reactor, **but the project has been shuttered due to China-U.S. trade tensions.** The company is now lobbying Congress for a public-private partnership to fund the reactor.

Despite the setbacks, Gates still seems optimistic about nuclear power's potential. "Nuclear is ideal for dealing with climate change because it is the **only carbon-free, scalable energy source that's available 24 hours a day**," Gates said. "The problems with today's reactors, such as the risk of accidents, can be solved through innovation."

Il nuovo progetto TerraPower – GE-Hitachi: il generatore e accumulatore di calore NATRIUM

E’ un reattore **a neutroni veloci** (che quindi può consumare le grandi riserve di energia ancora presenti nel combustibile irraggiato degli attuali reattori ad acqua: **Plutonio e Uranio 238**), refrigerato a **sodio liquido, che riscalda un grande serbatoio di sali fusi**.

Ha **una potenza di 345 MWe, che però può salire rapidamente anche oltre i 500 MWe per alcune ore**, sfruttando il calore accumulato nei sali fusi.

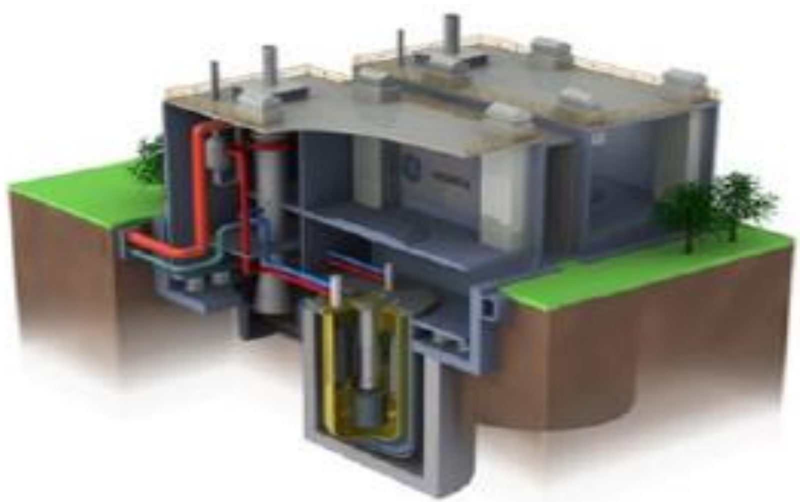
NATRIUM è quindi destinato a costituire **un efficace polo di integrazione e stabilizzazione** delle future reti elettriche comprendenti grandi contributi da **fonti intermittenti e non programmabili**, come la eolica e la solare.

world nuclear news

GEH and Southern team up on Prism

01 November 2016

GE Hitachi Nuclear Energy (GEH) and Southern Nuclear are to collaborate on the development and licensing of fast reactors including GEH's Prism sodium-cooled fast reactor, the companies announced yesterday.



GEH's vision of a Prism unit (Image: GEH)

From: http://www.world-nuclear-news.org/NN-GEH-and-Southern-team-up-on-Prism-0111168.html

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Prism is a **sodium cooled fast neutron reactor** design built on more than 30 years of development work, benefitting **from the operating experience of the EBR II** prototype integral fast reactor which operated at the USA's Idaho National Laboratory **from 1963 to 1994**.

Each Prism reactor has a rated thermal power of 840 MW and an electrical output of 311 MWe. **Two Prism reactors** make up a **power block, producing a combined total of 622 MW of electrical output**.

Using **passive safety**, **digital instrumentation and control**, and **modular fabrication techniques** to expedite plant construction, the design uses **metallic fuel, such as an alloy of zirconium, uranium, and plutonium**. It can therefore be used to **close the nuclear fuel cycle, recycling used nuclear fuel to generate energy**.

From: http://www.world-nuclear-news.org/NN-GEH-and-Southern-team-up-on-Prism-0111168.html

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According to GEH, commercialized **Prism technology could be used eventually to consume all the nuclear material contained in the world's used nuclear fuel**.

Assuming:

178,000 tonnes of nuclear material are contained in worldwide stocks of nuclear fuel and

a **per household consumption of 3400 kWh per year**,

the company claims this scenario could provide **enough energy to power the world's households for up to 200 years**.

GEH has proposed the **Prism reactor as a possible option for managing the UK's plutonium stockpile** (circa **120 tonnes**, which could supply all UK electricity for several years!).

From: http://www.world-nuclear-news.org/NN-GEH-and-Southern-team-up-on-Prism-0111168.html

world nuclear news
— Celebrating 15 years —

Energy & Environment | New Nuclear | Regulation & Safety | Nuclear Policies | Corporate | Uranium &

Macron sets out plan for French nuclear renaissance

11 February 2022

Share

France will construct six new nuclear power reactors, consider building a further eight and push ahead with the development of small modular reactors, President Emmanuel Macron has said.

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<Speaking at GE Steam Power's manufacturing site at Belfort in eastern France on Thursday, Macron, who faces a presidential election in April, said the main objective of the new policy was to reduce the country's energy consumption while increasing its carbon-free energy production capacity.

He said **in the coming decades France must produce more carbon-free electricity, because even if it reduces its energy consumption by 40%, the exit from oil and gas within 30 years implies that it will replace part of the consumption of fossil fuels with electricity**. The country must therefore be able to produce up to 60% more electricity than today.

"Key to producing this electricity in the most carbon-free, safest and most sovereign way is precisely to have a plural strategy ... **to develop both renewable and nuclear energies**," Macron stated.

"We have no other choice but to bet on these two pillars at the same time. It is the most relevant choice from an ecological point of view and the most expedient from an economic point of view and finally the least costly from a financial point of view.“>

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<New build programme

Secondly, Macron announced the launch of a programme of new reactors. "We have learned lessons from the construction of EPR in Finland, where it is now complete, and in France at Flamanville. **EDF has undertaken with the nuclear sector the design of a new reactor for the French market, the EPR2, which has already mobilised more than one million hours of engineering and presents significant progress compared with the EPR of Flamanville**.

"**I would like six EPR2s to be built and for us to launch studies on the construction of eight additional EPR2s," he said. "We will thus advance step by step**.“>

<In addition, Macron said EUR1.0 billion (USD1.1 billion) will be made available through the France 2030 re-industrialisation plan **for France's Nuward small modular reactor project and "innovative reactors to close the fuel cycle and produce less waste"**. He said he had set "an ambitious goal" to construct a first prototype in France by 2030.

"This new programme could lead to **the commissioning of 25 gigawatts of new nuclear capacity by 2050," Macron said**.>

WORLD NUCLEAR ASSOCIATION

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Nuclear Power in the United Kingdom

(Updated February 2022)

- The UK generates about 15-20% of its electricity from nuclear, but almost half of current capacity is to be retired by 2025.
- The UK has implemented a thorough assessment process for new reactor designs and their siting.
- The UK has privatized power generation and liberalized its electricity market, which together make major capital investments problematic.
- Construction has commenced on the first of a new generation of nuclear plants.

Operable Reactors | Reactors Under Construction | Reactors Shutdown

6,848 MWe | 3,260 MWe | 6,790 MWe

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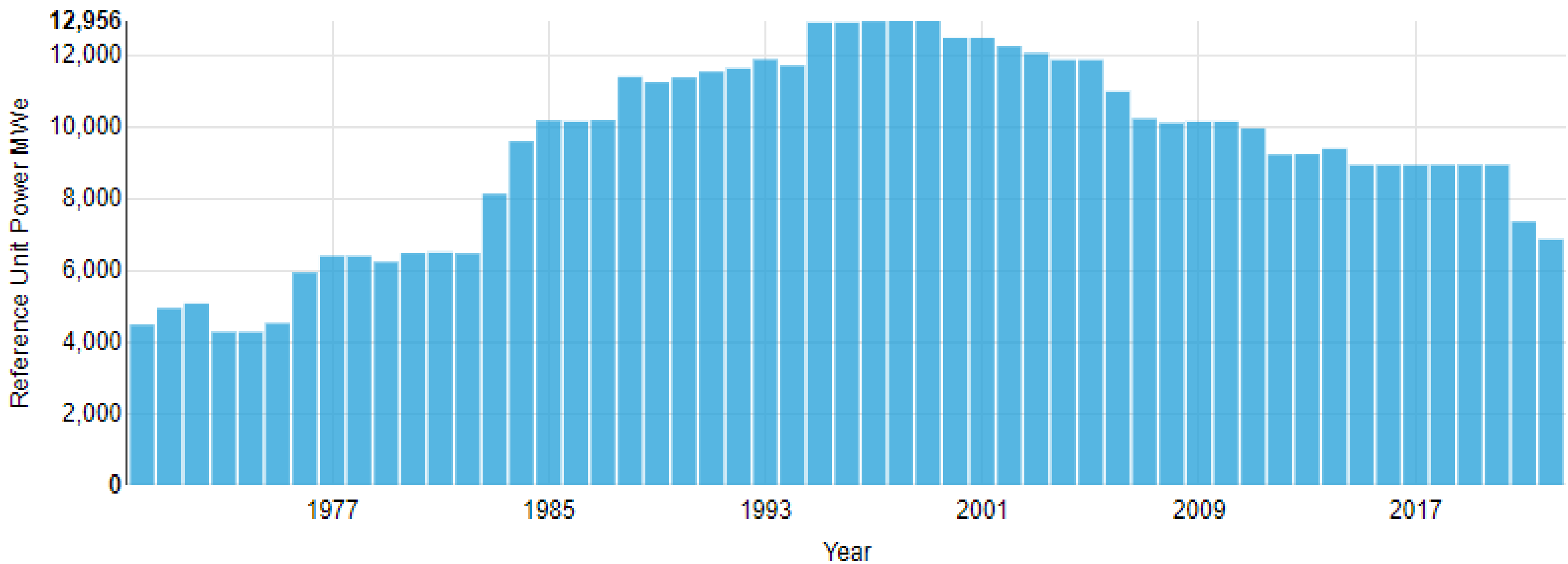
Operable nuclear power capacity



Electricity sector

Total generation (in 2019): 323 TWh

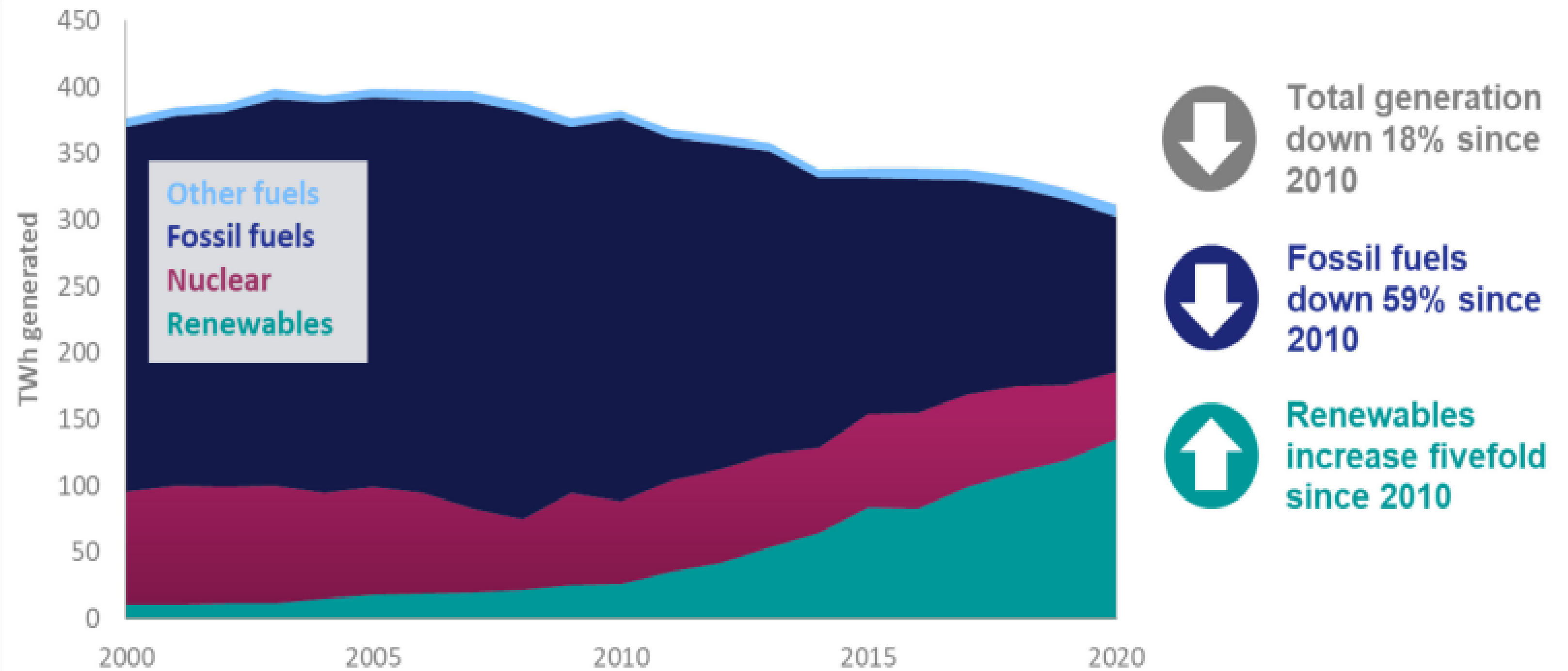
Generation mix: natural gas 131 TWh (40%); wind 64.3 TWh (20%); nuclear 56.2 TWh (17%); biofuels & waste 42.0 TWh (13%); solar 12.9 TWh (4%); hydro 7.7 TWh (2%); coal 7.7 TWh (2%).

Import/export balance: 21.2 TWh net import

Total consumption: 295 TWh

Per capita consumption: c. 4400 kWh in 2019

Chart 5.3 Electricity generation by fuel, 2000-2020 (Table 5.6)



Electricity generation fell to record low levels in 2020, with total electricity generation in 2020 of 312.0 TWh, 3.6 per cent less than in 2019. This reflects lower demand for electricity during 2020 as a result of the UK's Covid-19 restrictions. 2020 also continued the shift away from generation by Major Power Producers (MPPs), which was down 5.1 per cent to 253.9 TWh, partly offset by a 3.8 per cent increase in generation from autogenerators and other generators to 56.7 TWh. The generation by MPPs was the lowest value on the published data series, partly due to the lower demand but also the ongoing trend towards smaller renewable sites.

From:
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1006701/DUKES_2021_Chapter_5_Electricity.pdf

How much nuclear power does the UK use and is it safe?

4 days ago

Climate change

Hinkley Point C nuclear power station in Somerset

Boris Johnson says it's time to make "big new bets" on nuclear power so the UK's energy can become self-sufficient.

The prime minister said expanding the use of nuclear would help cut bills and resist "bullying" from Russia.

From: https://www.bbc.com/news/business-59212992 - March 19, 2022.

GOV.UK Topics

Home > Business and industry

News story

Nuclear energy: What you need to know

A summary of the benefits of nuclear power and what the government is doing to support its development in the UK.

From: Department for Business, Energy & Industrial Strategy, Prime Minister's Office, 10 Downing Street, The Rt Hon Kwasi Kwarteng MP, and The Rt Hon Boris Johnson MP

Published 6 April 2022

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What is the government currently doing to support nuclear power?

The strategy will see **a significant acceleration of nuclear, with an ambition of up to 24GW by 2050** to come from this safe, clean, and reliable source of power. This would represent up to **around 25% of our projected electricity demand**. Subject to technology readiness from industry, **Small Modular Reactors will form a key part of the nuclear project pipeline**.

A new government body, **Great British Nuclear**, will be set up immediately to bring forward new projects, backed by substantial funding, and we will launch the **£120 million Future Nuclear Enabling Fund** this month. We will work to progress a series of projects as soon as possible this decade, including **Wylfa** site in **Anglesey**. This could mean **delivering up to 8 reactors, equivalent to one reactor a year instead of one a decade, accelerating nuclear in Britain**.

We are committed to building the first new nuclear power station in a generation at **Hinkley Point C in Somerset, which will provide 3.2 GW** of secure, low carbon electricity for around 60 years to power around 6 million homes and provide 25,000 job opportunities.

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EDF are the lead investor building Hinkley Point C. They are targeting the first reactor coming online in June 2026. The developer is fully funding the project.

We have been in **constructive negotiations on the Sizewell C project** in Suffolk since January 2021, as the most advanced potential project in the UK. If approved **Sizewell C would be a replica of Hinkley Point C**, providing **electricity for 6 million homes**, and creating thousands of high value jobs nationwide.

In January we provided £100 million of funding for the Sizewell C developer to invest in the project to help bring it to maturity, attract investors, and advance to the next phase in negotiations.

As set out in the 2021 Spending Review, up to **£1.7 billion of funding is available** to support approval of at least one new nuclear power plant this Parliament.

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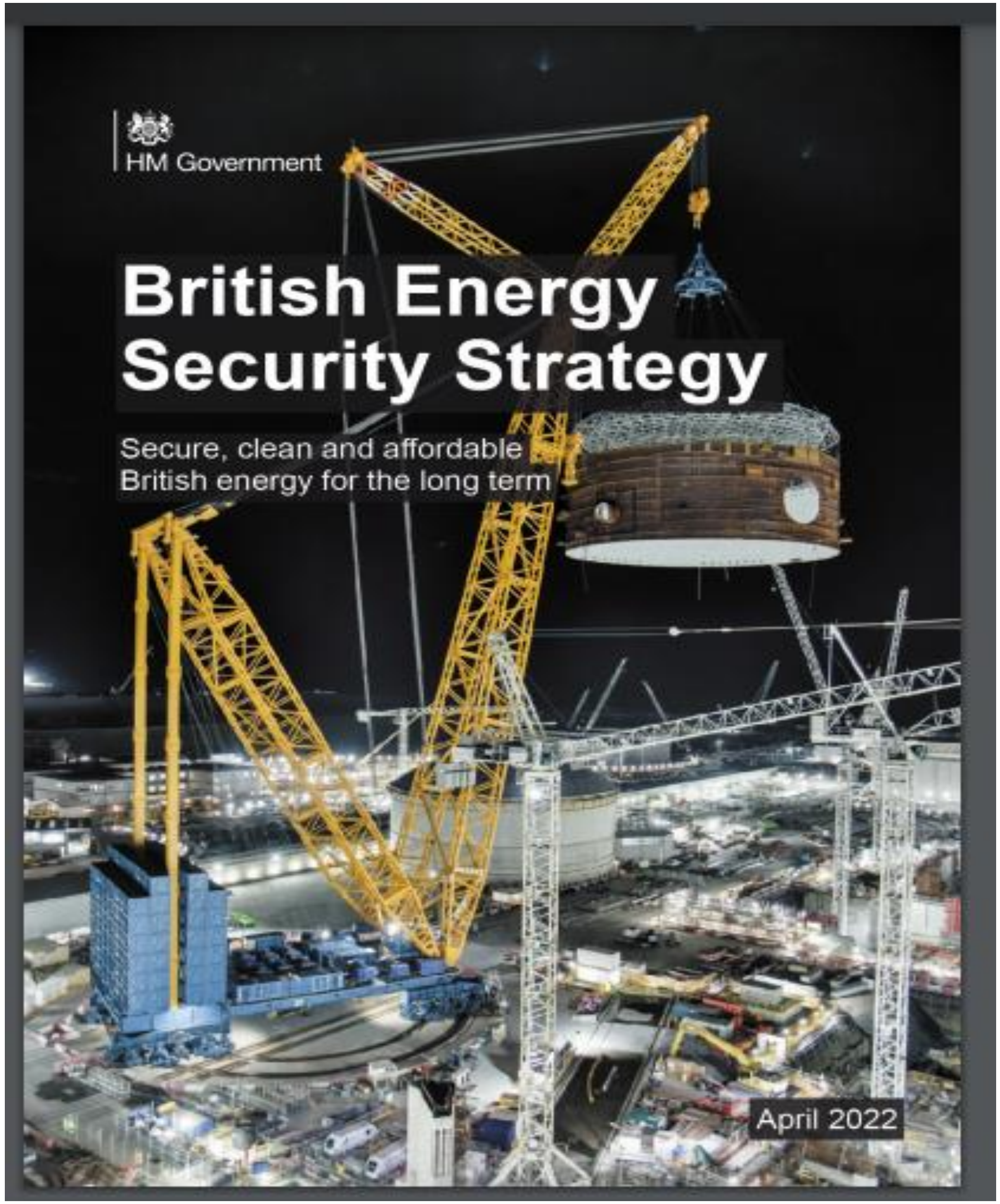
The **Nuclear Energy (Financing) Act** received Royal Assent last week. The Act will enable use of the **Regulated Asset Base funding** model for new nuclear projects, which will unblock obstacles to developing these projects and **cut the cost of financing them**.

The Advanced Nuclear Fund includes **up to £210 million announced in November 2021 for Rolls-Royce** to develop the design for one of the world's first **Small Modular Reactors**. This could be deployed in the UK in the early 2030s to turbocharge UK nuclear capacity.

We are also establishing a **new Future Nuclear Enabling Fund of up to £120 million** to provide targeted support **for new nuclear** and make it easier for new companies to enter the market.



From:
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067384/British_Energy_Security_Strategy.pdf

Small Nuclear Power Reactors

(Updated December 2021)

- There is strong interest in small and simpler units for generating electricity from nuclear power, and for process heat.
- This interest in small and medium nuclear power reactors is driven both by a desire to reduce the impact of capital costs and to provide power away from large grid systems.
- The technologies involved are numerous and very diverse.

From: https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx

Due accezione per SMR:

- **S**mall **M**edium **R**eactor
- **S**mall **M**odular **R**eactor

Gli «Small Medium and Modular Reactors»

Si tratta dei reattori di **“piccola” potenza** (cioè con potenze elettriche non superiori a **300 MWe**). Questa classe di reattori sta destando un crescente interesse: essi infatti sono adatti ad essere inseriti **in reti elettriche di limitate dimensioni**, o al servizio di **insediamenti isolati**.

La **costruzione modulare** permette di ottenere **anche centrali di alta potenza, ma in modo graduale**, in relazione alla crescita della domanda: **l’economia di scala** del grande impianto viene sostituita dalla **fabbricazione in serie ed in officina** dei piccoli impianti, in tempi molto più rapidi.

Sia negli **Stati Uniti** che in **Russia**, molti di questi progetti fanno **tesoro della loro lunghissima esperienza nella costruzione di reattori navali**.

I «piccoli reattori nucleari»: una storia tormentata e dimenticata (1/2)

Come detto, **«piccoli reattori»** vengono considerati quelli **di potenza inferiore a 300 MWe**, mentre i reattori oggi **in funzione** hanno una potenza media di circa **900 MWe**, e quelli **in costruzione** di circa **1000 MWe**.

Fin dagli **anni 1940**, **Aviazione, Esercito e Marina Americani** provarono ad usare piccoli reattori, dopo il «successo» delle armi nucleari. In 15 anni, l'**Aviazione** spese **un miliardo di dollari** (di allora) per sviluppare un reattore per **bombardieri a lungo raggio**, ma senza successo (anche per ovvie ragioni di sicurezza). Il Presidente Kennedy chiuse il programma.

I «piccoli reattori nucleari»: una storia tormentata e dimenticata (2/2)

Anche i piccoli reattori **dell’Esercito USA** non ebbero miglior fortuna: ne vennero **costruiti otto**, dislocati in basi remote, come **la Groenlandia o l’Antartide**.

Ma quello della base di **Mac Murdo, in Antartide**, a seguito di **guasti e perdite radioattive**, dovette essere **rispedito ad una base navale in California insieme a 14.000 metri cubi di terreno contaminato…**

Il programma venne **cancellato nel 1976**, e i reattori sostituiti con **generatori Diesel**!

USA 1950: i reattori ad acqua in pressione

Meglio invece l'impegno nella Marina Militare. Infatti, con l'avvio della "guerra fredda" negli anni 1950, la **Marina Militare delle Grandi Potenze** acquisì un ruolo strategico grazie **ai sottomarini ed alle portaerei equipaggiati con reattori nucleari**.

L'artefice di questa profonda evoluzione fu **l'Ammiraglio Hyman G. Rickover**, che rapidamente portò a maturità i reattori per uso navale: dopo un tentativo non convincente di reattore refrigerato con sodio liquido, **puntò su reattori refrigerati con acqua in pressione (Pressurized Water Reactor: PWR)**. La **Westinghouse** fu impegnata fin dall'inizio su questi reattori, ed in seguito anche la **General Electric** collaborò alla loro costruzione, e così la **Rolls Royce** per la inglese **Royal Navy**.

I reattori nucleari navali nel mondo

Francia, Cina e Russia procedettero in modo autonomo, sempre con **reattori PWR**, anche se la **Russia** dotò alcuni dei suoi sottomarini di **reattori veloci refrigerati da una miscela di piombo e bismuto fusi**.

Nel 1989, **alla fine della "guerra fredda"**, vi erano nel mondo **oltre 400 reattori per sottomarini, oltre a decine per portaerei ed incrociatori**. La **Russia** ha costruito, e continua a costruire, numerosi **rompighiaccio a propulsione nucleare**.

La sola **US Navy** ha utilizzato 500 "noccioli" di reattore, ed ha accumulato **5500 anni x reattore e 128 milioni di miglia senza alcun incidente nucleare**.

I reattori nucleari navali civili in Russia: una lunga tradizione

Late **February 2018**, the reactor on the ***Vaygach* nuclear icebreaker** steamed past what many thought a near impossible barrier, reaching **177,205 hours of operating time** – beating the record set by the *Arktika* nuclear icebreaker, whose reactor had run for one hour less when it was retired in 2008. **That's 7,383 and a half straight days, or just over 20 years**.

The **Vaygach was built in Finland in 1989** during the peak years of Mikhail Gorbachev's Glasnost, and its **KL-40 reactor** was installed at the **Baltic Shipyard in St. Petersburg**.

From: http://bellona.org/news/nuclear-issues/2018-03-russian-nuclear-icebreaker-reactor-sets-troubling-run-time-record

Vaygach nuclear icebreaker

From: http://bellona.org/news/nuclear-issues/2018-03-russian-nuclear-icebreaker-reactor-sets-troubling-run-time-record

I reattori nucleari navali civili in Russia: le nuove prospettive

L'obiettivo della Russia è il **potenziamento della flotta dei rompighiaccio nucleari**, con reattori in grado di spingerli anche a **10-12 nodi in ghiaccio spesso due metri**.

Questi rompighiaccio saranno destinati a mantenere per quanto possibile libera **la rotta orientale a nord della Siberia** per portare fino a **70 milioni di tonnellate all'anno il trasporto di merci verso l'Asia orientale**, evitando il Canale di Suez.

Recentemente, poi, è stato **varato** il nuovo **impianto nucleare galleggiante**, **l'Akademik Lomonosov**, destinato ad **aziende e basi isolate nel Grande Nord**.

LK-60 icebreakers, *Arktika*, able to handle **2.8 metres of ice**, are powered by **two RITM-200 reactors of 175 MWt each, together delivering 60 MWe** at the propellers via twin turbine-generators and three electric motors.

LK-60 icebreaker

From: http://www.world nuclear.org/information library/country-profiles/countries-o-s/russia-nuclear-power.aspx

A more powerful **LK-120 icebreaker** (project 10510) delivering **120 MWe** at four propellers is being designed, capable of breaking through **4.5 metre thick ice**, or 2 m thick ice at 14 knots. It is for deep-sea use especially in the eastern Arctic and will be 205 m long, 50 m wide and with 13 m draft, of 55,600 dwt. It will be powered by **two RITM-400 reactors of 315 MWt each.**

LK-120 icebreaker (project 10510)

From: https://lazerone.files.wordpress.com/2017/05/project-10510-sybir-a.png

Posted 30 Sep 2019 | 16:02 GMT

Photo: Evgeny Nipot/Russian State Television and Radio Broadcasting Company/Rosatom State Corporation

Tugboats prepare to tow the world's first floating nuclear plant to its destination in Russia's remote Far East.

The world's first floating nuclear power plant (FNPP) docked at Pevek, Chukotka, in Russia's remote Far East on 14 September. It completed a journey of some 9,000 kilometers from where it was constructed in a St. Petersburg shipyard. First, it was towed to the city of Murmansk, where its nuclear fuel was loaded, and from there took the North Sea Route to the other side of Russia's Arctic coast.

From: https://spectrum.ieee.org/energywise/energy/nuclear/is-the-world-ready-for-floating-nuclear-power-stations

Reattori per produrre calore e idrogeno (1/2)

Lo **European Green Deal (EGD)**, così come il **Piano Nazionale Energia e Clima (PNIEC) proposto dall'Italia**, sembrano **sottostimare** la decarbonizzazione delle **componenti energetiche "non elettriche"**, tuttora **nettamente preponderanti** nelle attuali economie avanzate.

Le **rinnovabili elettriche** (fotovoltaica, eolica) producono **solo energia elettrica** (e di pessima qualità: solo quando splende il sole o soffia il vento).

Si apre quindi una **vasta prospettiva** di applicazioni per **reattori nucleari di nuova concezione**, da utilizzare in contesti molto differenziati.

Reattori per produrre calore e idrogeno (2/2)

Il **reattore nucleare** infatti produce all'origine **tutta energia termica**, utilizzabile poi **in quanto tale**, o trasformabile in energia **elettrica o chimica o anche motrice** (come già visto, nei reattori navali).

Come vedremo, il sottoprodotto termico di **grandi centrali elettronucleari** già riscalda **ampie aree urbane**, mentre gli **SMR** possono fornire **riscaldamento e calore di processo**; tra questi, gli **Advanced Modular Reactors** (AMR) possono alimentare la **chimica ad alta temperatura** (produzione diretta dell'idrogeno, ecc.); ed infine, **very Small Modular Reactors** (vSMR), anche trasportabili, possono produrre **calore ed elettricità in aree prive di rete elettrica ed in condizioni climatiche estreme**.

Dall’UK, un esempio per lo EGD e il PNIEC

Un ottimo modello di riferimento può essere un documento dal titolo **"Achieving Net Zero: The role of Nuclear Energy in Decarbonisation"**, redatto dal **Nuclear Innovation and Research Advisory Board** (NIRAB) per conto del Department for Business, Energy and Industrial Strategy (BEIS) del Governo inglese. Esso afferma:

“Nuclear, as well as being a source of cost competitive electricity, can contribute to the production of heat and hydrogen to decarbonise other energy vectors."

e di conseguenza,

"Planning a future net zero energy system without significant nuclear energy would be extremely high risk."

nirab NUCLEAR INNOVATION AND RESEARCH ADVISORY BOARD

Supported by niro

Achieving Net Zero: The role of Nuclear Energy in Decarbonisation

A Report for the Department for Business, Energy and Industrial Strategy (BEIS)

Published April 2020

Further information about NIRAB is available at:
www.nirab.org.uk

Any enquiries about this report should be addressed to:
info@niro.org.uk

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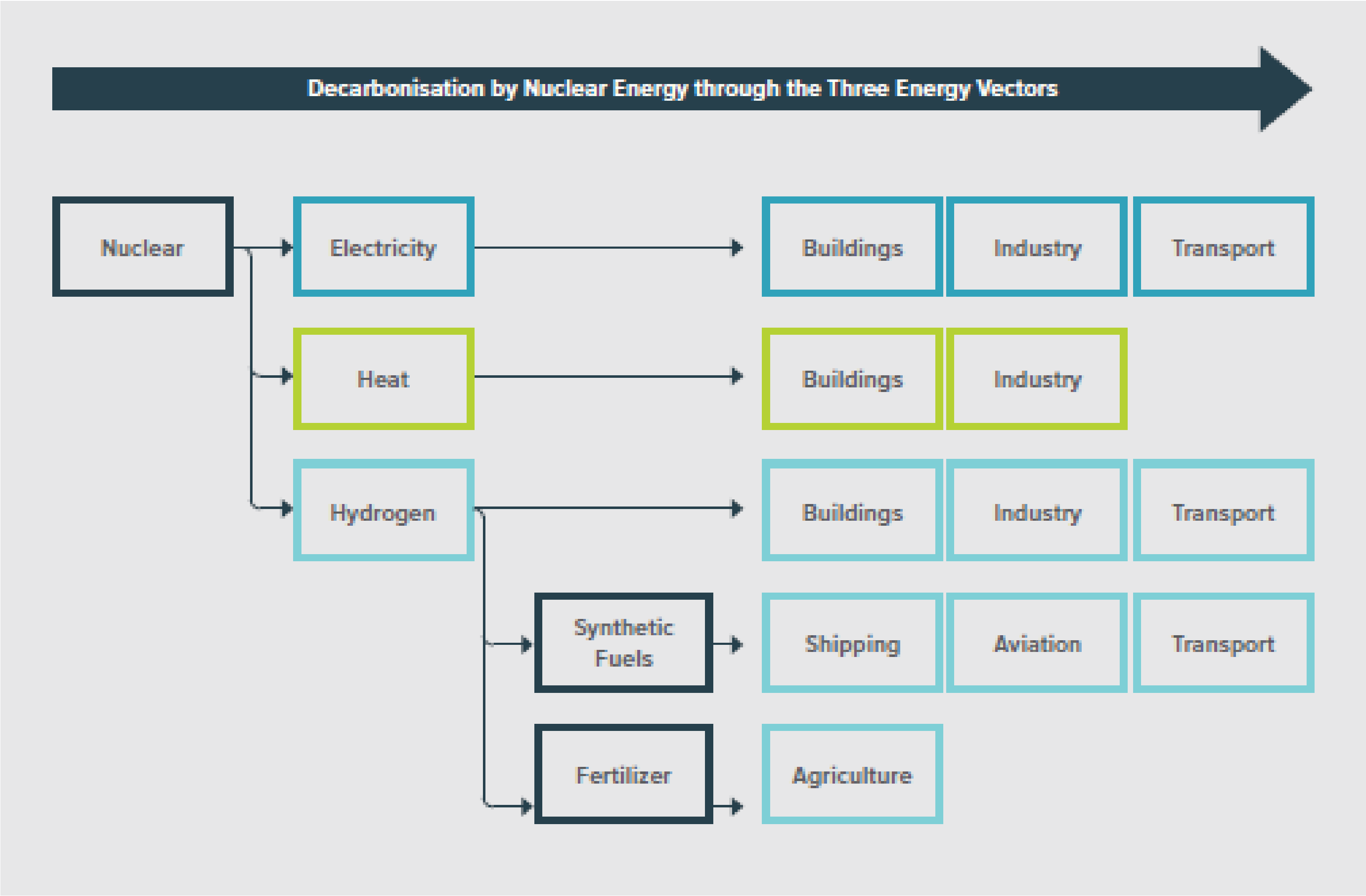

Figure 5 The role of nuclear in the deep decarbonisation of electricity, heat and hydrogen

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Il Regno Unito per la “carbon neutrality”

<**NIRAB** proposes that **three streams of nuclear product development and deployment** should be progressed to supply the energy needs of the population and support economic prosperity without impacting on climate change or air quality:

◁ **Large scale Light Water Reactors** (LWR), which are currently available and suitable for baseload electricity generation;

◁ **Small Modular Reactors (SMR)**, which are based on the same proven technology and can offer additional flexibility to meet local energy needs;

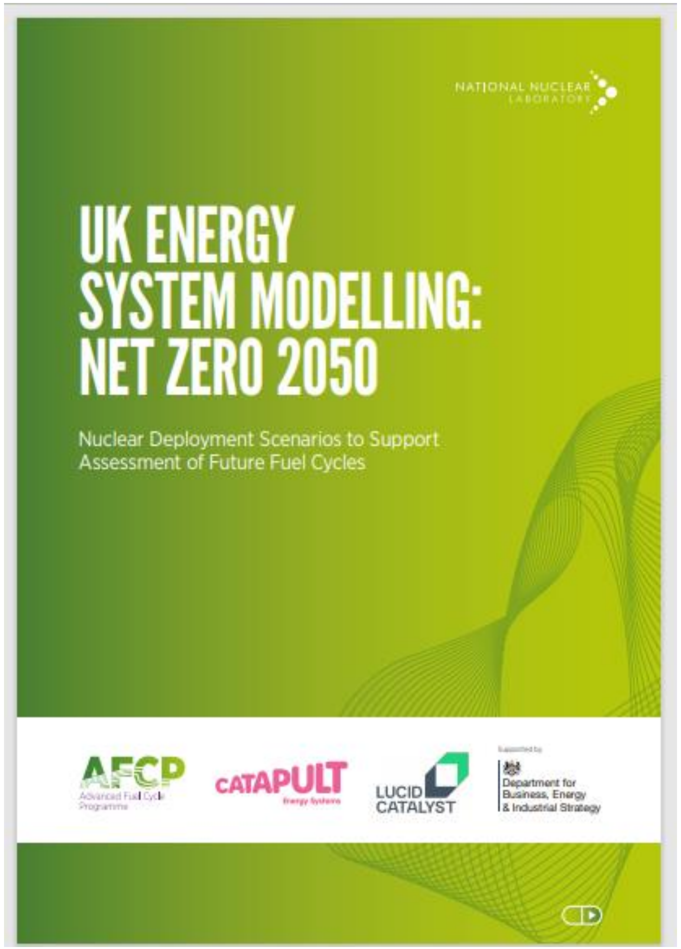
◁ **Advanced Modular Reactors (AMR)**, which typically have a higher temperature output, consequently enabling them to contribute to decarbonisation through heat and hydrogen production, as well as generate electricity at competitive costs.>

Un modello da seguire: prospettive per il nucleare in UK

Uno studio, commissionato **dall'UK's National Nuclear Laboratory** (NNL), analizza **quattro scenari energetici da raggiungere entro il 2050** nel **Regno Unito**, con **crescenti livelli di contributo da parte dell'energia nucleare**.

Questi sono:

- **Limitato dalla politica** a un livello massimo di 14 GWe di dispiegamento nucleare;
- **Caso base** (come quello **da poco annunciato dal Primo Ministro: almeno 24 GWe**);
- **Maggiore ottimismo**, con costi nucleari inferiori e un programma più "aggressivo" per l'introduzione sul mercato di **tecnologie nucleari avanzate**;
- **Maggiore ambizione nucleare**, con **nuove tecnologie per la produzione di idrogeno e combustibile sintetico**.



Nell’ultimo scenario, in particolare, vi sono due progetti altamente promettenti: una **Gigafactory** volta alla produzione sia di **idrogeno a basso costo** e a ridotto impatto ambientale, sia alla produzione di **carburante sintetico liquido** (o synfuel) per applicazioni "drop-in" nel settore dell'**aviazione** senza emissioni nette di carbonio.

L'immagine seguente mostra una **Gigafactory a idrogeno con spazio a sufficienza per 36 reattori.**

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2. Hydrogen gigafactory

2.1. Overview

The **Hydrogen Gigafactory** would manufacture and operate **nuclear reactors as high-temperature heat sources** to create large quantities of **low-cost, carbon-free hydrogen (H2**). The following image shows a Hydrogen Gigafactory with **space for 36 reactors**. The buildings on the left include **the heat source manufacturing facility** (larger building) and **precast facility** (smaller building). At the top in the middle is **the finished bank of 12 reactors** installed below grade with blue hatches, along **with their heat exchanger 'pods'** with green hatches. Preparation and installation are underway in the other two banks in the middle. **Each reactor is 600 MWt and 250 MWe (42% efficiency)**.

Figure A1.1 – Conceptual illustration with modular manufacturing and assembly building at rear, hydrogen gigafactory under construction beneath the yellow cranes, adjacent hydrogen manufacturing plant and liquid synthetic fuel manufacturing plant in the foreground

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LucidCatalyst describes the **Hydrogen Gigafactory** concept in the forthcoming report for the Electric Power Research Institute titled Clean and Scalable Synthetic Fuels as follows:

• **The 'factory' configuration is a highly productive**, dedicated **manufacturing facility where the high-temperature heat sources are fabricated and installed on site**. Hydrogen production is also on the same site. **The heat sources are small modular 600 MWt units** with a complementary **modular heat exchanger unit which transfers the heat to the molten-salt heat-supply network for the thermochemical hydrogen plant**. **Rail and port access** is adjacent to the manufacturing facility, **allowing the manufacturing plant to transport high-value components** that are not necessarily used at the facility when the construction of the plant is complete.

• For this modelling project, the earliest potential operation year for the Hydrogen Gigafactory in the UK **is 2030**, and **the construction period is 2 years**. **Nuclear reactors are then manufactured and installed after construction at the factory site**. The maximum potential build rate for the Gigafactory ramps up **from 5 GWe in 2030 to 10 GWe per year from 2040 onwards**. The **economic and technical life is 60 years**. The technology has a peak contribution factor of 95% and **annual availability factor of 92%.** It has **a flexibility factor of 50%,** which reflects the facility's **capacity to sell power from the nuclear reactors directly to the UK grid if necessary**, based on ESME's simulation of power market conditions (*).

(*) The ESME model is a proprietary model owned by the Energy Technologies Institute (ETI).

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2.2. Inputs and outputs

The **Hydrogen Gigafactory uses 1.923 kWh of nuclear fuel energy as input to produce each kWh of hydrogen** output (**52% efficiency**). This operational conversion efficiency comes from a 2003 report on the use of high-temperature nuclear heat for hydrogen production from General Atomics.

The following figure provides a process schematic of the Hydrogen Gigafactory.

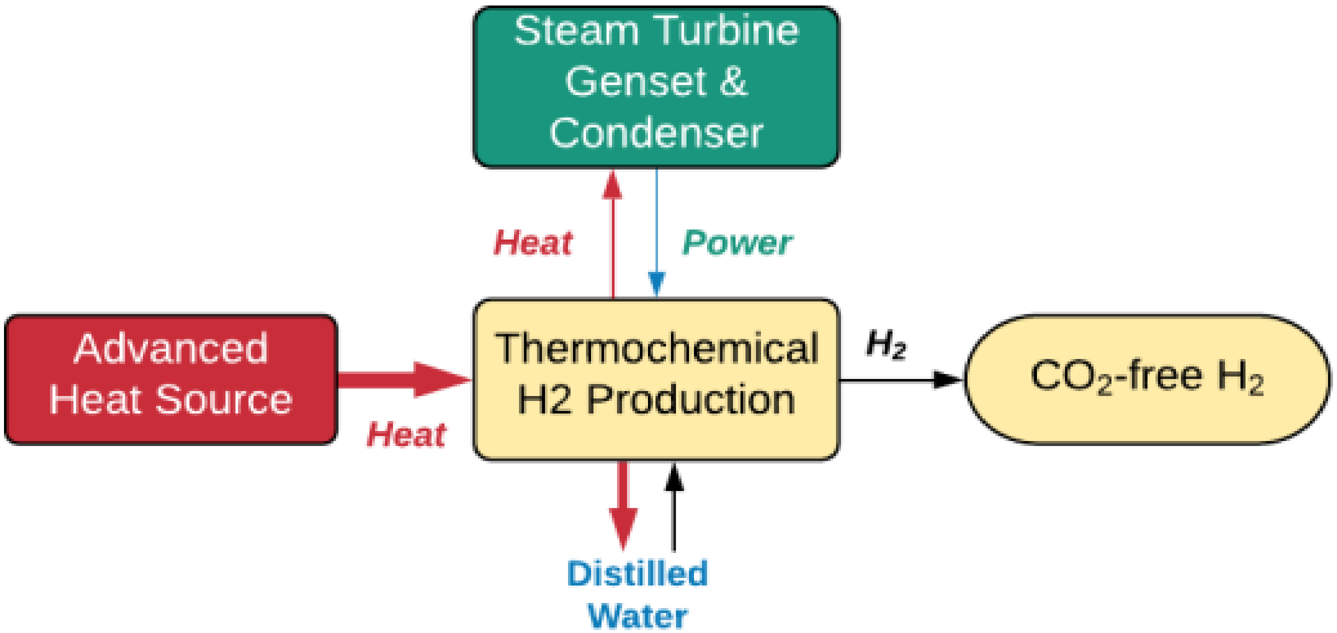

Figure A1.2 – Schematic of hydrogen gigafactory

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3. Liquid synthetic fuel plant

3.1. Overview

Each liquid synthetic fuel plant would use **heat and power from a nuclear reactor to produce hydrogen**, which would then be **combined with carbon to produce 'drop-in' liquid synthetic aviation fuel** ('Jet A'). The carbon could come from various source options. **Biogenic carbon** from biofuels **or the air or sea** would provide **the full potential climate mitigation benefit**, because in this case the carbon extraction would **reduce the carbon concentration in the environment** leading to climate change. Alternatively, the carbon for synthetic fuel production could come **from capture and storage of emissions from fossil fuel use** (such as coal plants), but this would provide only half the climate benefit of using biogenic carbon because the fossil fuel carbon has been brought up from geological deposits.

The earliest potential operation year for the liquid synthetic fuels plant in the UK is 2030, and **the construction period is 4 years**. The maximum potential build rate ramps up **from 5 GWe in 2030 to 10 GWe per year from 2040 onwards**. **The economic and technical life is 60 years**. The technology has a peak contribution factor of 95% and annual availability factor of 92%

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3.2. Inputs and outputs

The following figure provides a process schematic of the liquid synthetic fuels plant.

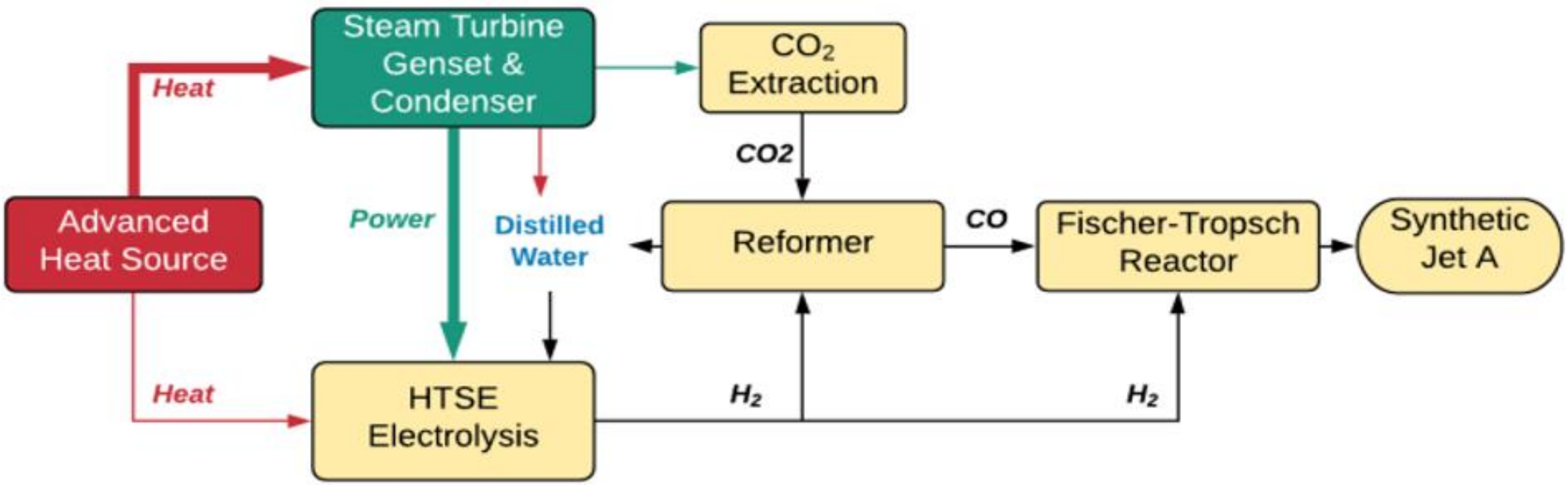

Figure A1.2 – Schematic of liquid synthetic fuels plant **HTSE: High Temperature** Steam **Electrolysis**.

LucidCatalyst divided the liquid synthetic fuels plant into three systems for the ESME modelling: (1) **nuclear to hydrogen**; (2) **hydrogen to Jet A**; and (3) **carbon processing**. The nuclear-to-hydrogen system uses **2.5 kWh of nuclear fuel energy to produce 1.326 kWh of hydrogen** output (**52% system efficiency**) as well as **0.250 kWh of high-temperature heat**. The second system uses the **hydrogen and heat output** from the first system to produce **each kWh of Jet A** (**40% overall efficiency relative to nuclear fuel energy input**). The operating efficiencies for the synthetic liquid fuel plant derive from analysis in LucidCatalyst's forthcoming report on Clean and Scalable Synthetic Fuels. As described above, each tonne of carbon embedded in the Jet A from the plant must come **from a biogenic source** for maximum climate benefit, **or from carbon captured and stored** from fossil fuel use for half as much climate benefit.

ADVANCES IN SMALL MODULAR REACTOR TECHNOLOGY DEVELOPMENTS

2020 Edition

A Supplement to:
IAEA Advanced Reactors Information System (ARIS)
http://aris.iaea.org

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The 2020 edition comprises of six (6) parts arranged in the order of the different types of coolants, the neutron spectrum adopted, and the sixth part is dedicated for microreactors, as a new sub-category within SMR and to cover other SMRs that do not use the traditional coolants and/or fuel design, such as heat pipes.

Table 1: Design and Status of SMRs included in this Booklet

Design	Output MW(e)	Type	Designers	Country	Status
PART 1: WATER COOLED SMALL MODULAR REACTORS (LAND BASED)					
CAREM	30	PWR	CNEA	Argentina	Under construction
ACP100	100	PWR	CNNC	China	Detailed Design
CANDU SMR	300	PHWR	Candu Energy Inc (SNC-Lavalin Group)	Canada	Conceptual Design
CAP200	200	PWR	SNERDI/SPIC	China	Conceptual Design
DHR400	400 MW(t)	LWR (pool type)	CNNC	China	Basic Design
HAPPY200	200 MW(t)	PWR	SPIC	China	Detailed Design
TEPLATOR™	50 MW(t)	HWR	UWB Pilsen & CIIRC CTU	Czech Republic	Conceptual Design
NUWARD	2 × 170	PWR	EDF, CEA, TA, Naval Group	France	Conceptual Design
IRIS	335	PWR	IRIS Consortium	Multiple Countries	Basic Design
DMS	300	BWR	Hitachi-GE Nuclear Energy	Japan	Basic Design
IMR	350	PWR	MHI	Japan	Conceptual Design
SMART	107	PWR	KAERI and K.A.CARE	Republic of Korea, and Saudi Arabia	Certified Design
RITM-200	2 × 53	PWR	JSC "Afrikantov OKBM"	Russian Federation	Under Development
UNITHERM	6.6	PWR	NIKIET	Russian Federation	Conceptual Design
VK-300	250	BWR	NIKIET	Russian Federation	Detailed Design
KARAT-45	45 - 50	BWR	NIKIET	Russian Federation	Conceptual Design
KARAT-100	100	BWR	NIKIET	Russian Federation	Conceptual Design
RUTA-70	70 MW(t)	PWR	NIKIET	Russian Federation	Conceptual Design
ELENA	68 kW(e)	PWR	National Research Centre "Kurchatov Institute"	Russian Federation	Conceptual Design
UK SMR	443	PWR	Rolls-Royce and Partners	United Kingdom	Conceptual Design
NuScale	12 × 60	PWR	NuScale Power Inc.	United States of America	Under Regulatory Review
BWRX-300	270 - 290	BWR	GE-Hitachi Nuclear Energy and Hitachi GE Nuclear Energy	United States of America, Japan	Pre-licensing
SMR-160	160	PWR	Holtec International	United States of America	Preliminary Design
W-SMR	225	PWR	Westinghouse Electric Company, LLC	United States of America	Conceptual Design
mPower	2 × 195	PWR	BWX Technologies, Inc	United States of America	Conceptual Design
PART 2: WATER COOLED SMALL MODULAR REACTORS (MARINE BASED)					
KLT-40S	2 × 35	PWR in Floating NPP	JSC Afrikantov OKBM	Russian Federation	In Operation
RITM-200M	2 × 50	PWR in FNPP	JSC Afrikantov OKBM	Russian Federation	Under Development
ACPR50S	50	PWR in FNPP	CGNPC	China	Conceptual Design
ABV-6E	6-9	PWR in FNPP	JSC Afrikantov OKBM	Russian Federation	Final design
VBER-300	325	PWR in FNPP	JSC Afrikantov OKBM	Russian Federation	Licensing Stage

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SHELF	6.6	PWR in Immersed NPP	NIKIET	Russian Federation	Detailed Design
PART 3: HIGH TEMPERATURE GAS COOLED SMALL MODULAR REACTORS					
HTR-PM	210	HTGR	INET, Tsinghua University	China	Under Construction
StarCore	14/20/60	HTGR	StarCore Nuclear	Canada/UK/US	Pre-Conceptual Design
GTHTR300	100 - 300	HTGR	JAEA	Japan	Pre-licensing
GT-MHR	288	HTGR	JSC Afrikantov OKBM	Russian Federation	Preliminary Design
MHR-T	4 × 205.5	HTGR	JSC Afrikantov OKBM	Russian Federation	Conceptual Design
MHR-100	25 – 87	HTGR	JSC Afrikantov OKBM	Russian Federation	Conceptual Design
PBMR-400	165	HTGR	PBMR SOC Ltd	South Africa	Preliminary Design
A-HTR-100	50	HTGR	Eskom Holdings SOC Ltd.	South Africa	Conceptual Design
HTMR-100	35	HTGR	Steenkampskraal Thorium Limited	South Africa	Conceptual Design
Xe-100	82.5	HTGR	X-Energy LLC	United States of America	Basic Design
SC-HTGR	272	HTGR	Framatome, Inc.	United States of America	Conceptual Design
HTR-10	2.5	HTGR	INET, Tsinghua University	China	Operational
HTTR-30	30 (t)	HTGR	JAEA	Japan	Operational
RDE	3	HTGR	BATAN	Indonesia	Conceptual Design
PART 4: FAST NEUTRON SPECTRUM SMALL MODULAR REACTORS					
BREST-OD-300	300	LMFR	NIKIET	Russian Federation	Detailed Design
ARC-100	100	Liquid Sodium	ARC Nuclear Canada, Inc.	Canada	Conceptual Design
4S	10	LMFR	Toshiba Corporation	Japan	Detailed Design
microURANUS	20	LBR	UNIST	Korea, Republic of	Pre-Conceptual Design
LFR-AS-200	200	LMFR	Hydromine Nuclear Energy	Luxembourg	Preliminary Design
LFR-TL-X	5~20	LMFR	Hydromine Nuclear Energy	Luxembourg	Conceptual Design
SVBR	100	LMFR	JSC AKME Engineering	Russian Federation	Detailed Design
SEALER	3	LMFR	LeadCold	Sweden	Conceptual Design
EM^2	265	GMFR	General Atomics	United States of America	Conceptual Design
Westinghouse LFR	450	LMFR	Westinghouse Electric Company, LLC.	United States of America	Conceptual Design
SUPERSTAR	120	LMFR	Argonne National Laboratory	United States of America	Conceptual Design
PART 5: MOLTEN SALT SMALL MODULAR REACTORS					
Integral MSR	195	MSR	Terrestrial Energy Inc.	Canada	Conceptual Design
smTMSR-400	168	MSR	SINAP, CAS	China	Pre-Conceptual Design
CA Waste Burner 0.2.5	20 MW(t)	MSR	Copenhagen Atomics	Denmark	Conceptual Design
ThorCon	250	MSR	ThorCon International	International Consortium	Basic Design
FUJI	200	MSR	International Thorium Molten-Salt Forum: ITMSF	Japan	Experimental Phase
Stable Salt Reactor - Wasteburner	300	MSR	Moltex Energy	United Kingdom / Canada	Conceptual Design
LFTR	250	MSR	Flibe Energy, Inc.	United States of America	Conceptual Design
KP-FHR	140	Pebble-bed salt cooled Reactor	KAIROS Power, LLC.	United States of America	Conceptual Design
Mk1 PB-FHR	100	FHR	University of California at Berkeley	United States of America	Pre-Conceptual Design
MCSFR	50 - 1200	MSR	Elysium Industries	USA and Canada	Conceptual Design

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PART 6: MICRO MODULAR REACTORS					
Energy Well	8	FHTR	Centrum výzkumu Řež	Czech Republic	Pre-Conceptual Design
MoveluX	3~4	Heat Pipe	Toshiba Corporation	Japan	Conceptual Design
U-Battery	4	HTGR	Urenco	United Kingdom	Conceptual Design
Aurora	1.5	FR	OKLO, Inc.	United States of America	Conceptual Design
Westinghouse eVinci	2 -3.5	Heat Pipe	Westinghouse Electric Company, LLC.	United States of America	Under Development
MMR	5-10	HTGR	Ultra Safe Nuclear Corporation	United States of America	Preliminary Design

Part One: Land-based water-cooled SMRs. This part presents notable water-cooled SMR designs from various configurations of light water reactor (LWR) and heavy water reactor (HWR) technologies for on-land on-the-grid applications. These designs represent the mature technology considering most of the large power plants in operation today are of water-cooled reactors. There are twenty-five (25) water-cooled SMR designs from 12 Member States described in this booklet that comprises integral-PWRs, compact-PWRs, loop-PWRs, BWRs, CANDU-type designs, and pool-type reactors for district heating. An integral-PWR with natural circulation, designated as CAREM is finalizing construction for operation by 2023. Dozens of designs are being prepared for near-term deployment, including the ACP-100 in China and NuScale in the United States.

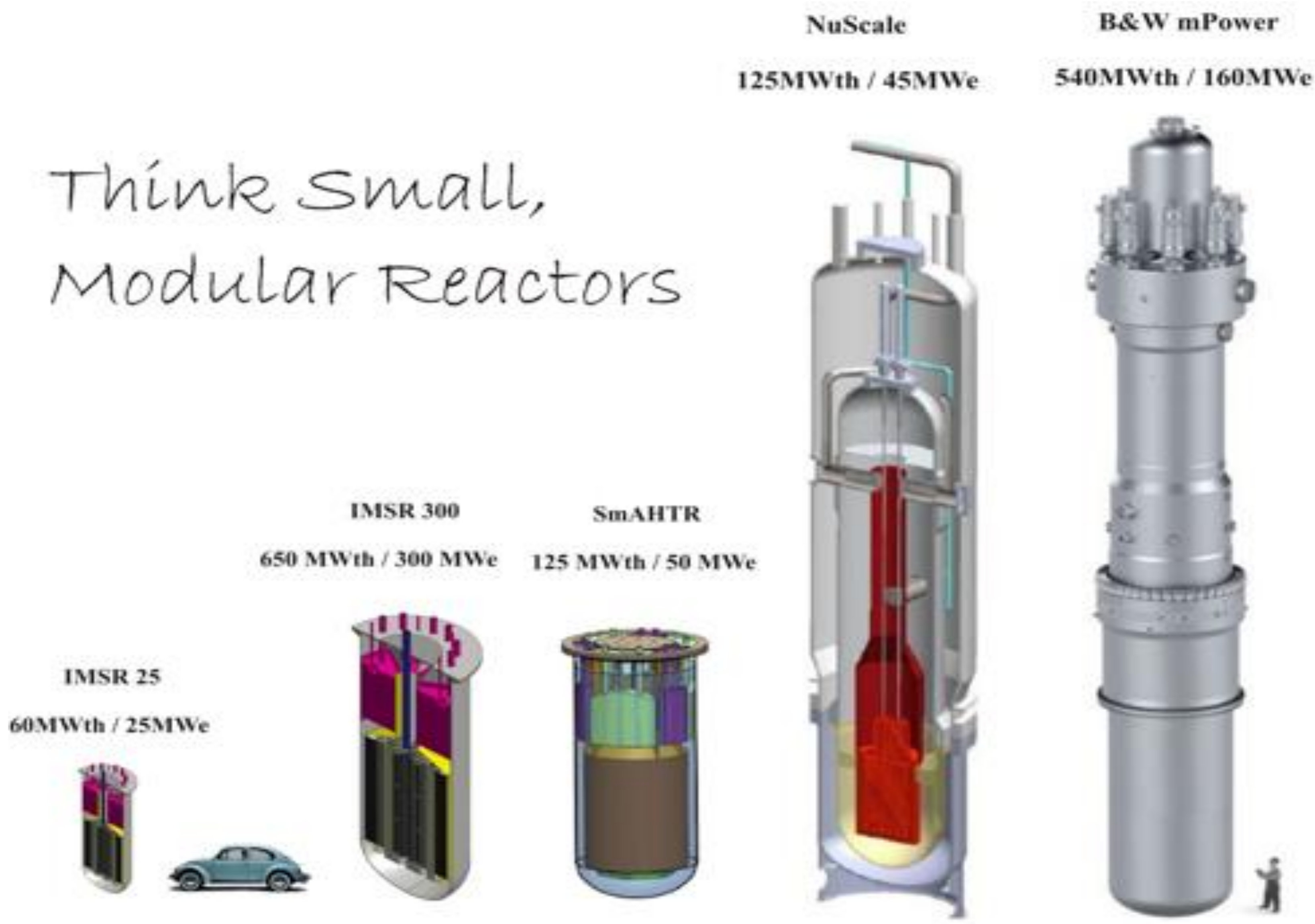
Part Two: Marine-based water-cooled SMRs. This part presents concepts that can be deployed in a marine environment, either as barge-mounted floating power unit or immersible underwater power unit. This unique application provides many flexible deployment options. This booklet presents six (6) marine-based water-cooled SMRs, some of them have been deployed as nuclear icebreaker ships. The first SMR connected to the grid is from this category, with the deployment KLT-40S for the Akademik Lomonosov floating nuclear power plant in Pevek, Russian Federation that started commercial operation in May 2020.

Part Three: High Temperature Gas Cooled SMRs: This part provides information on the modular type HTGRs under development and under construction. HTGRs provide high temperature heat (≥750°C) that can be utilized for more efficient electricity generation, a variety of industrial applications as well as for cogeneration. Eleven (11) HTGR-type SMRs are described in this booklet, including HTR-PM, which is the next SMR to start operation in 2021 in China and three (3) HTGR test-reactors, two that have been in operation for technology testing purposes in Japan and China for over twenty years.

Part Four: Fast Neutron Spectrum SMRs. This part presents eleven (11) SMR designs that adopt fast neutron spectrum with all different coolant options, including sodium, heavy liquid metal (e.g. lead or lead-bismuth) and helium-gas. Tangible advances in technology development and deployment on SMRs in this category have been made. The BREST-OD-300, a lead-cooled fast neutron reactor is in the process of construction at a site in Seversk, Russian Federation with a scheduled operation by end of 2026. This is a demo-prototype project for future design with large power to enable a closed nuclear fuel cycle.

Part Five: Molten Salt SMRs. This part highlights ten (10) SMR designs from molten salt fuelled and cooled advanced reactor technology (MSRs), which is also one of the six Generation IV reactor designs. MSRs promise many advantages including enhanced safety due to salt's inherent property, low-pressure single-phase coolant system that eliminates the need of large containment, a high temperature system that results in high efficiency, and flexible fuel cycle. Several MSR designs are conducting preliminary licensing activities in Canada, United Kingdom and the United States.

Part Six: Micro-sized SMRs. This booklet now contains a dedicated part to present advances on microreactors. An unprecedented development trend emerged on very small SMRs designed to generate electrical power of typically up to 10 MW(e). They are from different types of coolant, including HTGRs and designs that use heat pipes for heat transport. Several designs are undertaking licensing activities in Canada and the United States for planned near-term deployment. In 2019 a site application was submitted by Global First Power for a single small modular reactor using USNC's Micro Modular Reactor (MMR) technology at the Chalk River Laboratories site. Microreactors serve future niche electricity and district heat markets in remote regions, mining, industries and fisheries that for decades have been served by diesel power plants. Six (6) microreactor designs are included and discussed in this booklet.



From: http://nextbigfuture.com/2016/05/international-tokomak-fusion-project.html

world nuclear news

CNL selects first SMR vendors for cost-shared funding

18 November 2019

Share

Kairos Power, Moltex Canada, Terrestrial Energy Inc and UltraSafe Nuclear Corporation (USNC) have been selected as the first recipients of support under an initiative launched earlier this year to accelerate the deployment of small modular reactors (SMRs) in Canada, Canadian Nuclear Laboratories (CNL) has announced.

CNL aims to provide a global hub for SMR research and technology, and plans to have a demonstration SMR built on site by 2026. It launched the Canadian Nuclear Research Initiative (CNRI) in July to accelerate SMR deployment by enabling research and development and connecting global vendors of SMR technology with the facilities and expertise within Canada's national nuclear laboratories. Recipients are expected to match the value contributed by CNL either in monetary or in-kind contributions.

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The **four projects** that have been selected are:

- **Moltex Canada** and the University of New Brunswick's test apparatus to explore the potential of **converting used Candu reactor fuel** to power their stable salt reactor design;
- **Terrestrial Energy**'s evaluation of nuclear safety, security and non-proliferation technologies for its **integrated molten salt reactor** (IMSR400) and other SMR designs. The Terrestrial Energy project will also look at opportunities to use CNL's existing facilities, notably the ZED-2 reactor, as well as develop new experimental capabilities related to molten salt reactors.
- **Kairos Power**'s tritium management strategy for its **high-temperature fluoride salt-cooled** reactor;
- **USNC**'s resolution of technical issued for its **Micro Modular Reactor** (MMR), including fuel processing, reactor safety, and fuel and graphite irradiation.

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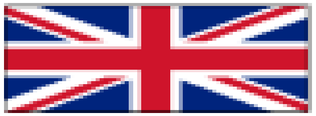
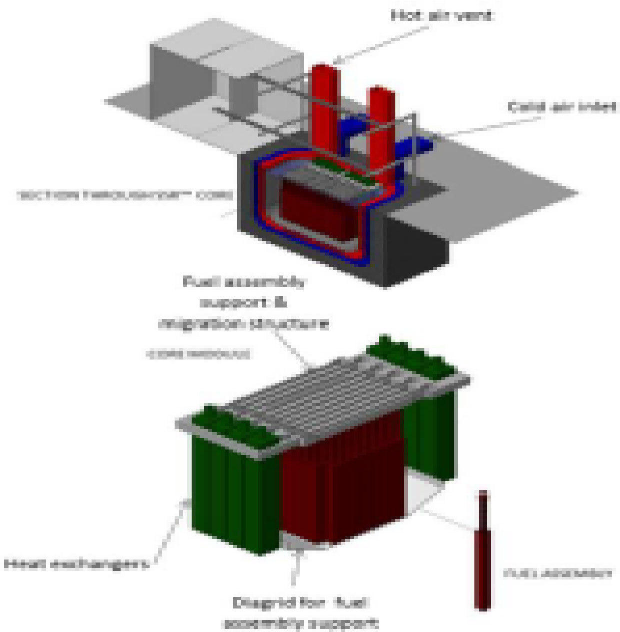
Moltex said the award would support its ongoing **Oxide Nuclear WAste Reduction Demonstration project**. This is exploring the commercial viability of Moltex's **WAste To Stable Salts (WATSS)** technology **to convert used Candu fuel into new fuel for a Stable Salt Reactor.**

Rory O'Sullivan, Moltex Energy CEO for North America, said: **"Many countries around the world have stores of used nuclear fuel from their current nuclear plants and we have discovered a clean, safe and economical way to recycle this waste into a fuel to produce power in the Moltex Stable Salt Reactor, and significantly reduce the amount of long-lived radionuclides."**



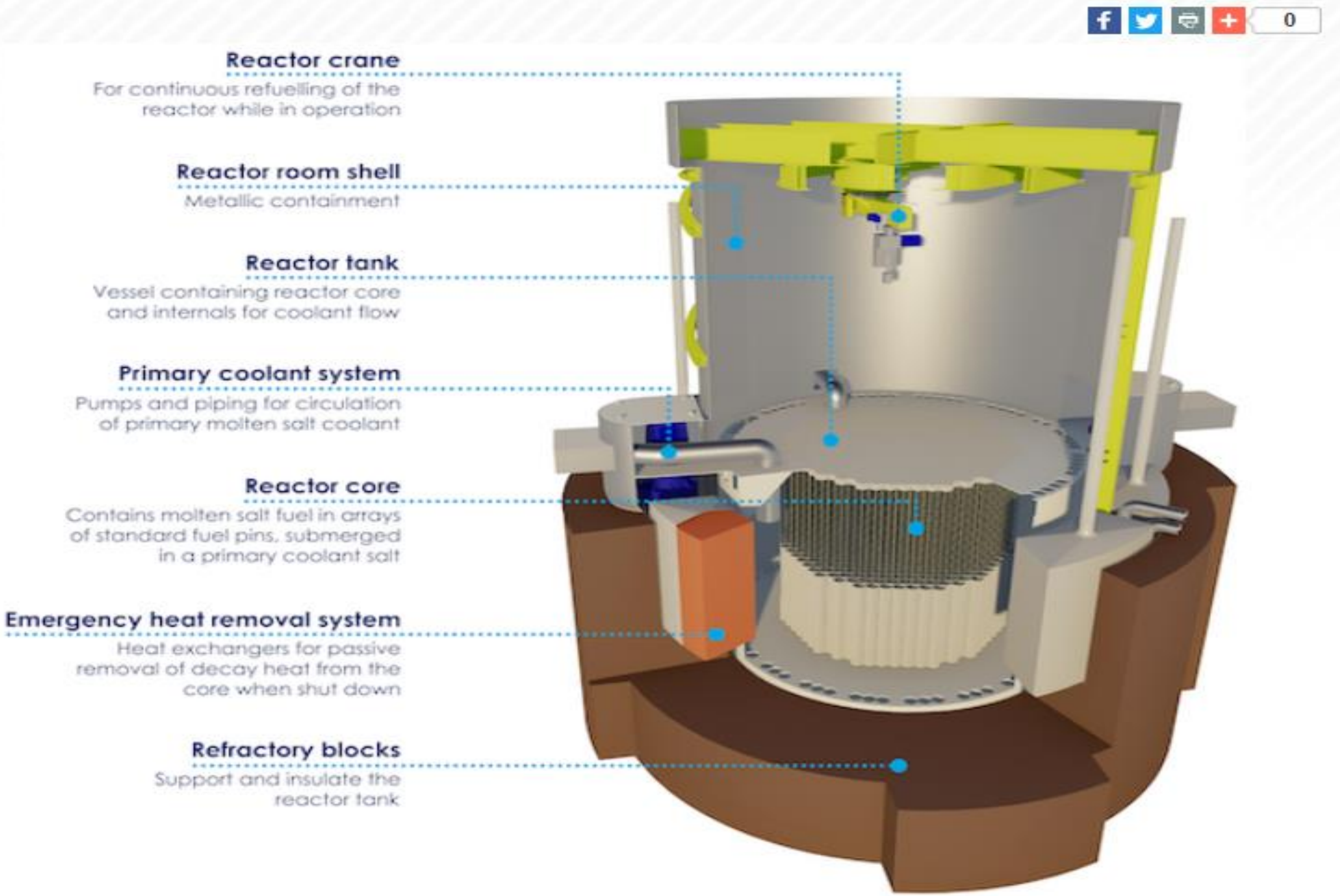
Stable Salt Reactor - Wasteburner (Moltex Energy, UK)



MAJOR TECHNICAL PARAMETERS	
Parameter	**Value**
Technology developer, country of origin	Moltex Energy, United Kingdom
Reactor type	Static fuelled molten salt fast reactor
Coolant/moderator	No moderator. Coolant is molten salt ZrF4/KF/NaF
Thermal/electrical capacity, MW(t)/MW(e)	750/300 continuous as baseload 750/900 as 8 hour peaking plant
Primary circulation	Forced circulation
System pressure (MPa)	Atmospheric
Core inlet/exit temperatures (°C)	500/630
Fuel salt	Molten salt fuel within vented fuel tubes in a conventional style fuel assembly
Number of fuel assemblies	200
Fuel enrichment (%)	Reactor grade plutonium
Fuel burnup (GWd/ton)	>300
Fuel cycle (months)	~150
Main reactivity control mechanism	Boron carbide control assemblies
Approach to engineered safety systems	Hierarchy is eliminate hazard, then passive engineering then active engineering
Design life (years)	60
Plant footprint (m²)	22500
Tank height/length/width (m)	5/6/5/
Seismic design	Yes
Distinguishing features	Molten salt fuel in conventional fuel assemblies; thermal energy storage to allow operation as peaking plant; very low cost conversion of spent LWR fuel into SSR fuel
Design status	Concept, Canadian vendor design review in progress

From: https://aris.iaea.org/publications/smr-book_2018.pdf

The waste-burning Stable Salt Reactor



From: The waste-burning Stable Salt Reactor - Image558225 - Nuclear Engineering International (neimagazine.com)

1. Introduction

The Stable Salt Reactor (SSR) is unique in its use of molten salt fuel replacing solid pellets in conventional fuel assemblies. This brings the major advantages of safe molten salts without the technical hurdles of managing a mobile liquid fuel. The reactor is fuelled with very low purity, reactor grade plutonium recycled from stocks of spent uranium oxide fuel and produced by a low cost process called WATSS (Waste to Stable Salt). The reactor outputs its heat as a stream of molten nitrate salts which can be stored in large volume at low cost making the reactor a low-cost peaking power plant rather than being restricted to baseload operation. This same system permits the entire steam cycle to be identical to the low-cost steam system in CCGT power stations and for it to be operated completely independently of the nuclear plant and not subject to nuclear regulations.

2. Target Application

The SSR Wasteburner is designed for countries with significant stocks of spent nuclear fuel. The reactor burns the full higher actinide component of that fuel leaving a relatively short lived, fission product only, waste stream. The fuel cost is expected to be negative, net of the reduced liability cost for disposal of the original spent fuel. It is designed to be capable of economically efficient electrical power peaking but with the reactor itself running at constant power. It therefore fills the need in national power systems for a low carbon complement to intermittent renewable energy sources.

From: https://aris.iaea.org/publications/smr-book_2018.pdf

WATSS: turning nuclear waste into fuel

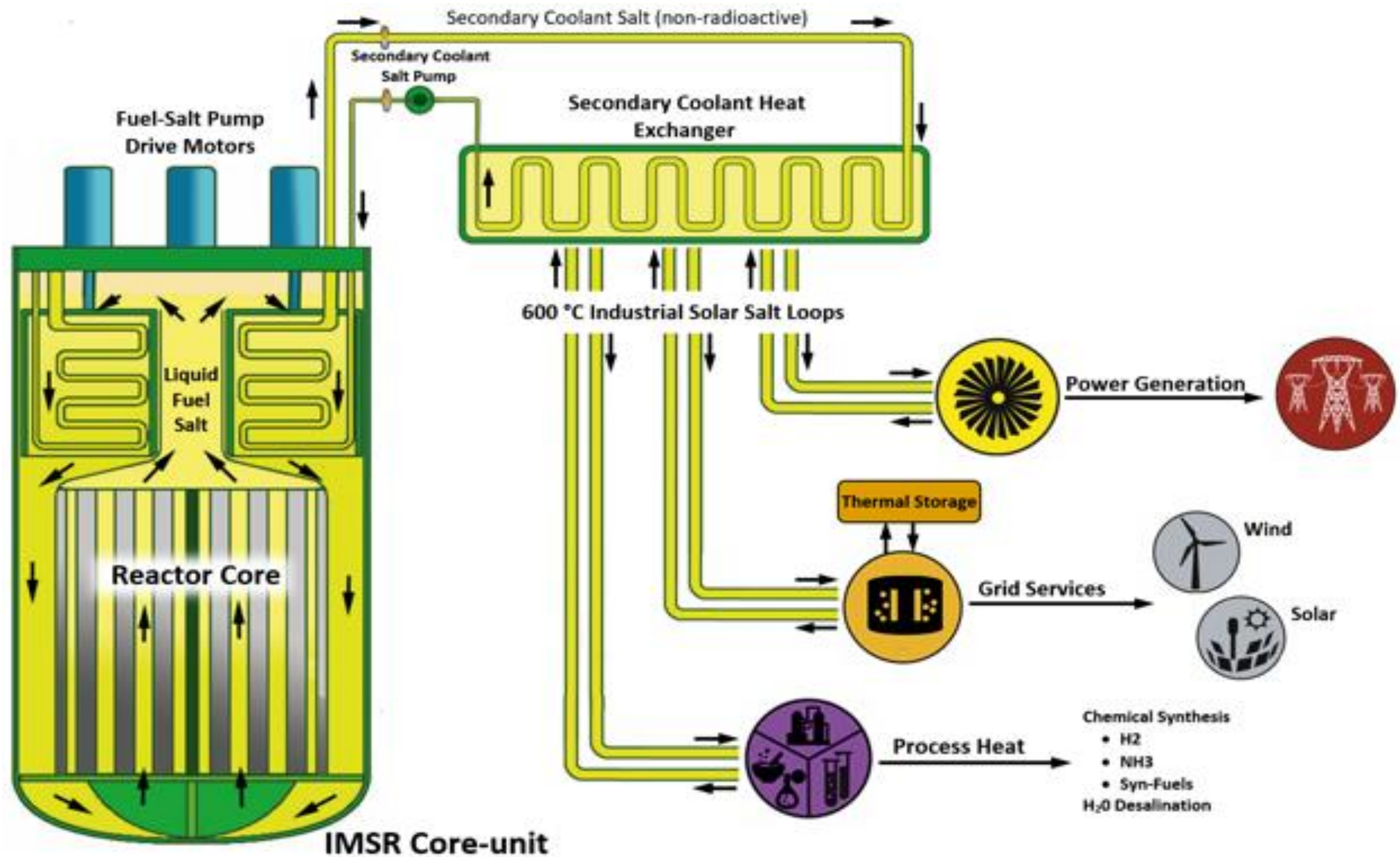
What makes the Watss process economically viable is that the **SSR reactor does not need high-purity fuel**. It needs the **higher actinides as fissile material**, but they can be **mixed with both unused uranium and lanthanide fission products**.

Highly radioactive, long-lived CANDU waste enters this process. **What comes out is**:

- A **small volume (about 1/100th of the input spent fuel)** of highly radioactive but **relatively short-lived salt**, produced during the extraction process. Depending on the country, the salt can be disposed of in conventional deep geological repositories (about 500m deep) or down 5km deep boreholes in geologically stable rock. It could **also be used in a heat battery** and non-radioactive fission products could be **recovered as a source of rare earth metals**.
- **Zircaloy sheathing material that could be reused** as an alloying element in a metal fuel or as a redox agent in a liquid fuel or coolant, or disposed of as intermediate level waste.
- **Depleted uranium**, with **very low radioactivity and negligible heat generation**, that can be safely and inexpensively stored until the uranium has a value that makes it worth recycling. There are also a number of intermediate and long-term storage options available in the event this by-product is not recycled.
- **Fuel for the SSR**, which **can be recycled** until all the higher actinides are consumed.

From: https://www.neimagazine.com/features/featurethe-waste-burning-stable-salt-reactor-9563796/

The **Integral Molten Salt Reactor (IMSR)** (1/2)



The **Integral Molten Salt Reactor (IMSR)** is a design for a small modular reactor(SMR) that employs molten salt reactor technology being developed by the Canadian company **Terrestrial Energy**.

From: https://en.wikipedia.org/wiki/Integral_Molten_Salt_Reactor

The **Integral Molten Salt Reactor (IMSR)** (2/2)

The **Integral Molten Salt Reactor** is so called because it integrates into a **compact, sealed and replaceable nuclear reactor unit**, called the **IMSR Core-unit**.

The unit include all the primary components of the nuclear reactor that operate on the **liquid molten fluoride salt fuel**: moderator, primary heat exchangers, pumps and shutdown rods.[6]

The Core-unit forms the heart of the IMSR system. In the Core-unit, **the fuel salt is circulated between the graphite core and heat exchangers**.

From: https://en.wikipedia.org/wiki/Integral_Molten_Salt_Reactor

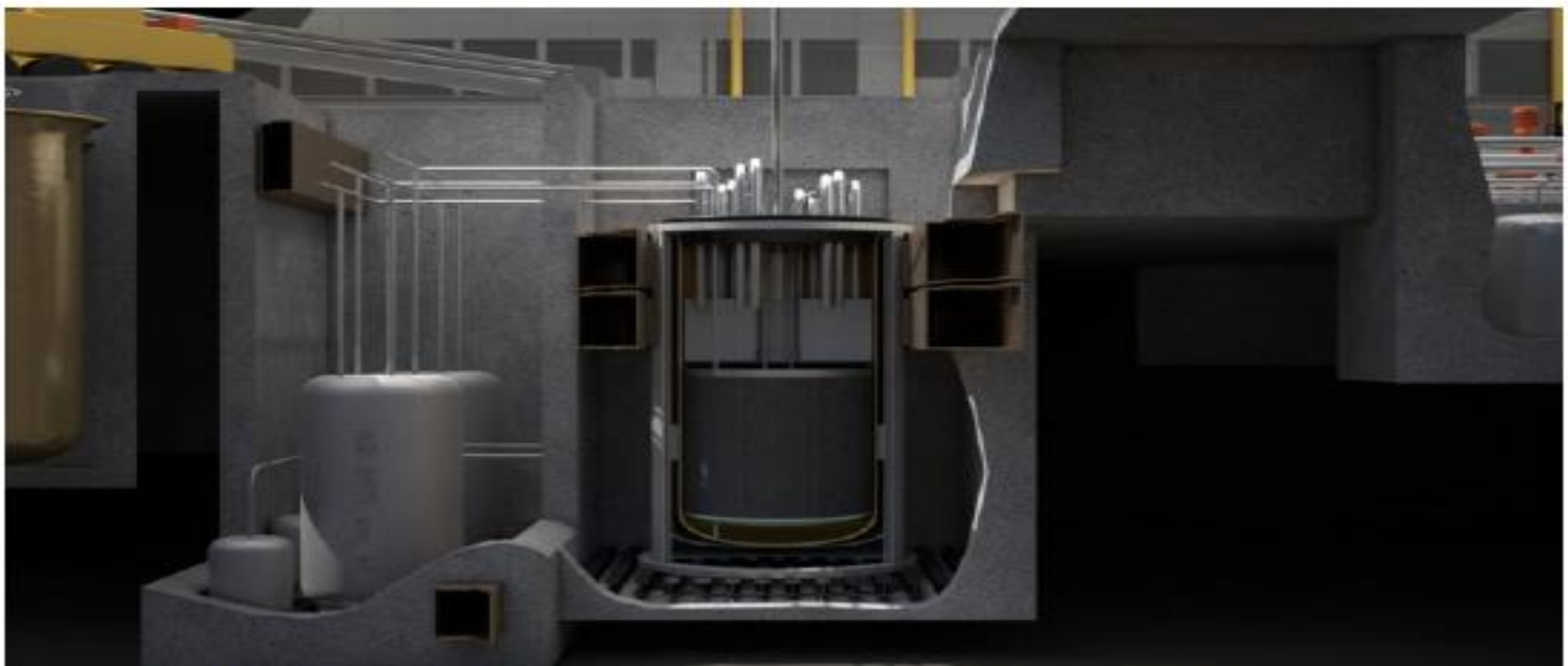
world nuclear news

Detailed testing of IMSR fuel salt starts

11 November 2020

Share

Terrestrial Energy and the US Department of Energy's Argonne National Laboratory (ANL) have begun detailed testing of the fuel salt for Terrestrial's Integral Molten Salt Reactor (IMSR). The IMSR uses two molten salt streams - a fuel salt that contains the uranium and another salt to transfer heat from the reactor to the electricity generation system.



A cutaway of the IMSR (Image: Terrestrial Energy)

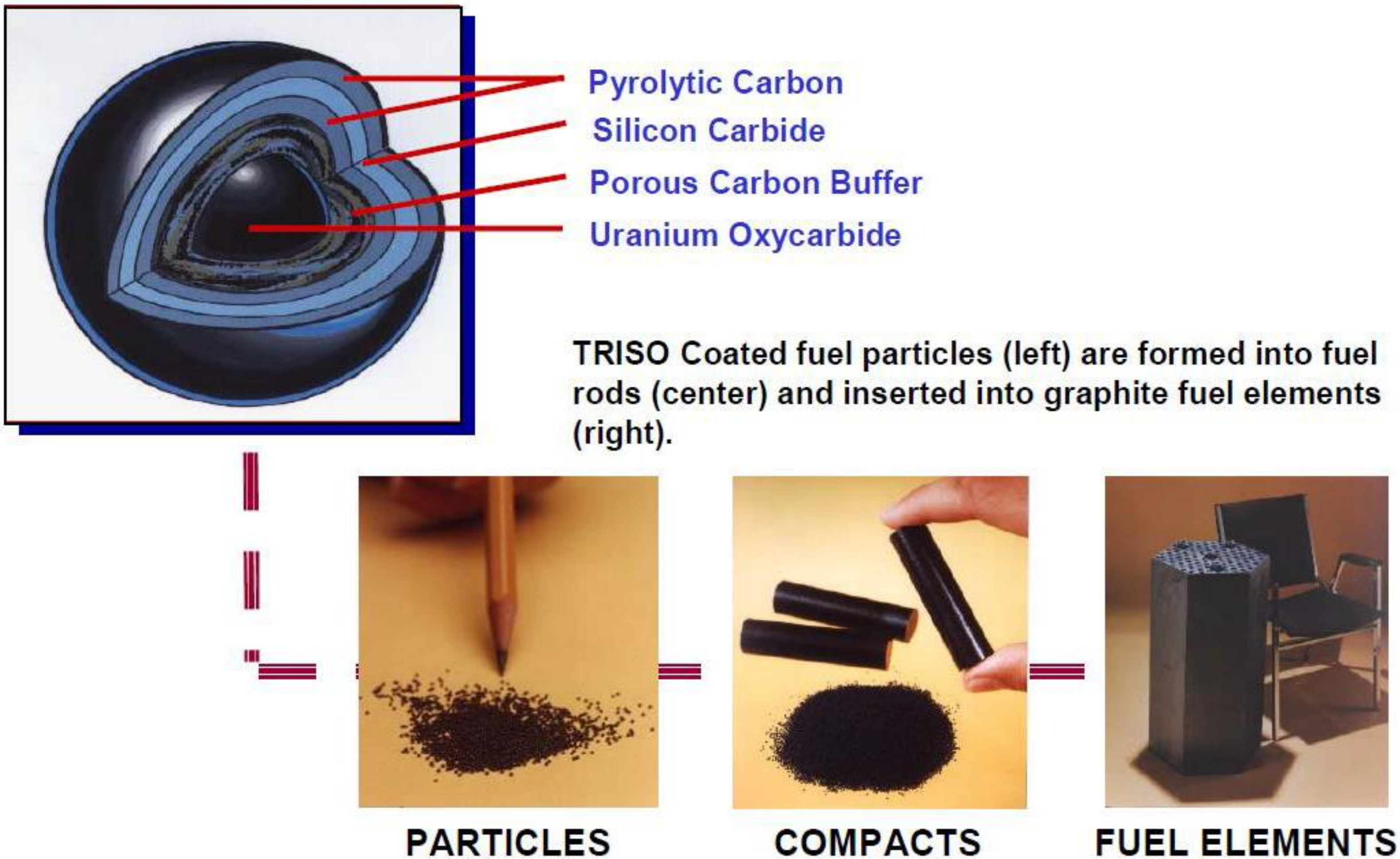
Kairos Power e **USNC** usano combustibile TRISO (TRi-Structural ISOtropic Particle Fuel): che cos'è?

Si tratta di particelle costituite da un ***kernel* di combustibile, ossidi o carburi di fissile e fertile**. Il *kernel* è poi rivestito da **tre strati di materiali a base di grafite** che impediscono il rilascio di prodotti di fissione radioattivi.

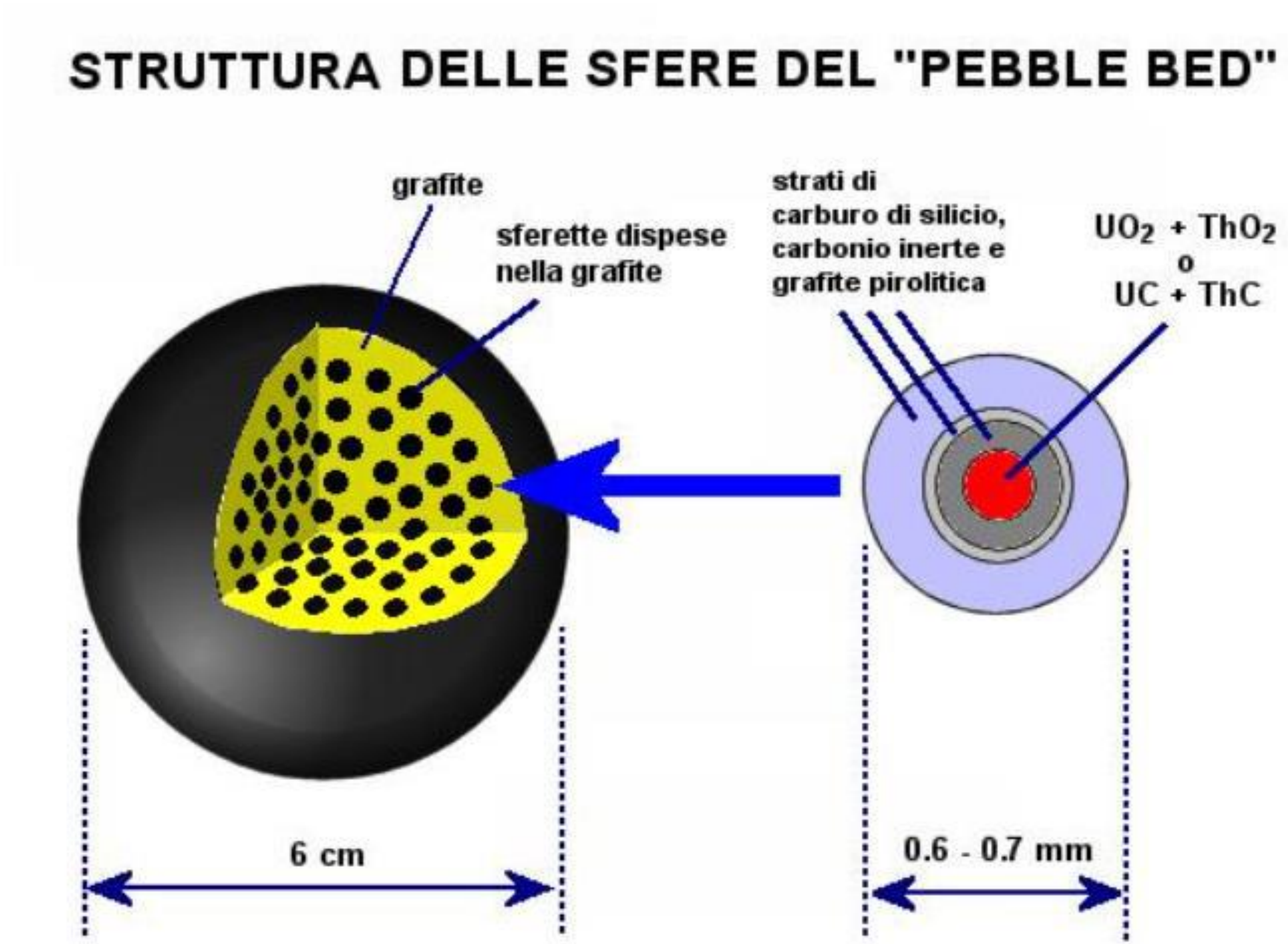
Il punto forte di questo combustibile sta nella sicurezza: ogni particella agisce come un vero e proprio **sistema di contenimento grazie ai suoi strati a triplo rivestimento**, consentendo di trattenere i prodotti di fissione in tutte le condizioni del reattore, sia operative che accidentali.

Il rischio di una **fusione del nocciolo è fisicamente impossibile**: la particella TRISO ha una temperatura limite di 1600-1800 °C, la densità volumetrica di potenza nei noccioli è relativamente bassa e la potenza è distribuita in più moduli, ognuno con il suo sistema di emergenza.

Da: «Impianti nucleari di piccola potenza per la cogenerazione - Produzione di Idrogeno e Teleriscaldamento» Tesi di Lorenzo Labardi – Sapienza Università di Roma - A.A. 2019-2020.

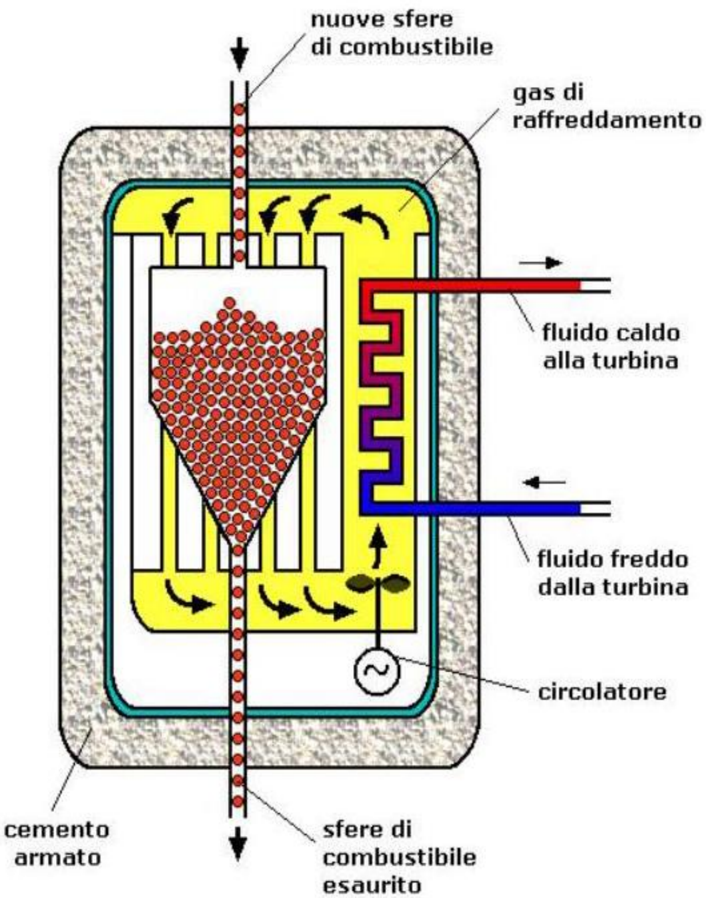


Da: «Impianti nucleari di piccola potenza per la cogenerazione - Produzione di Idrogeno e Teleriscaldamento» Tesi di Lorenzo Labardi – Sapienza Università di Roma - A.A. 2019-2020.



Da: «Impianti nucleari di piccola potenza per la cogenerazione - Produzione di Idrogeno e Teleriscaldamento» Tesi di Lorenzo Labardi – Sapienza Università di Roma - A.A. 2019-2020.

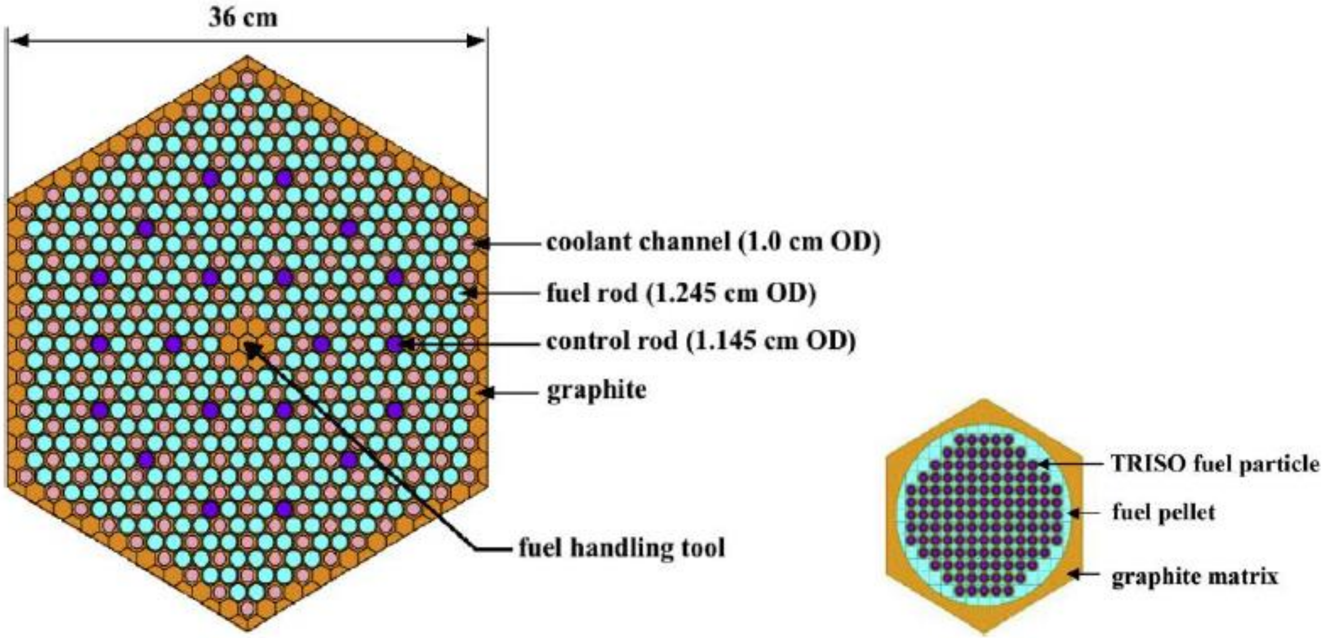
schema di reattore "pebble bed"



Nella configurazione Pebble-bed il nocciolo è costituito da migliaia di sfere (diametro 60 mm) realizzate immergendo le particelle TRISO in una matrice di grafite, che opera da moderatore dello spettro neutronico. Il controllo della reattività è eseguito con piccole sfere assorbenti (SAS: Small Absorber Spheres) mischiate a quelle di combustibile o con barre di controllo che possono essere calate nel riflettore e fra le sfere del nocciolo.

Da: «Impianti nucleari di piccola potenza per la cogenerazione - Produzione di Idrogeno e Teleriscaldamento» Tesi di Lorenzo Labardi – Sapienza Università di Roma - A.A. 2019-2020.

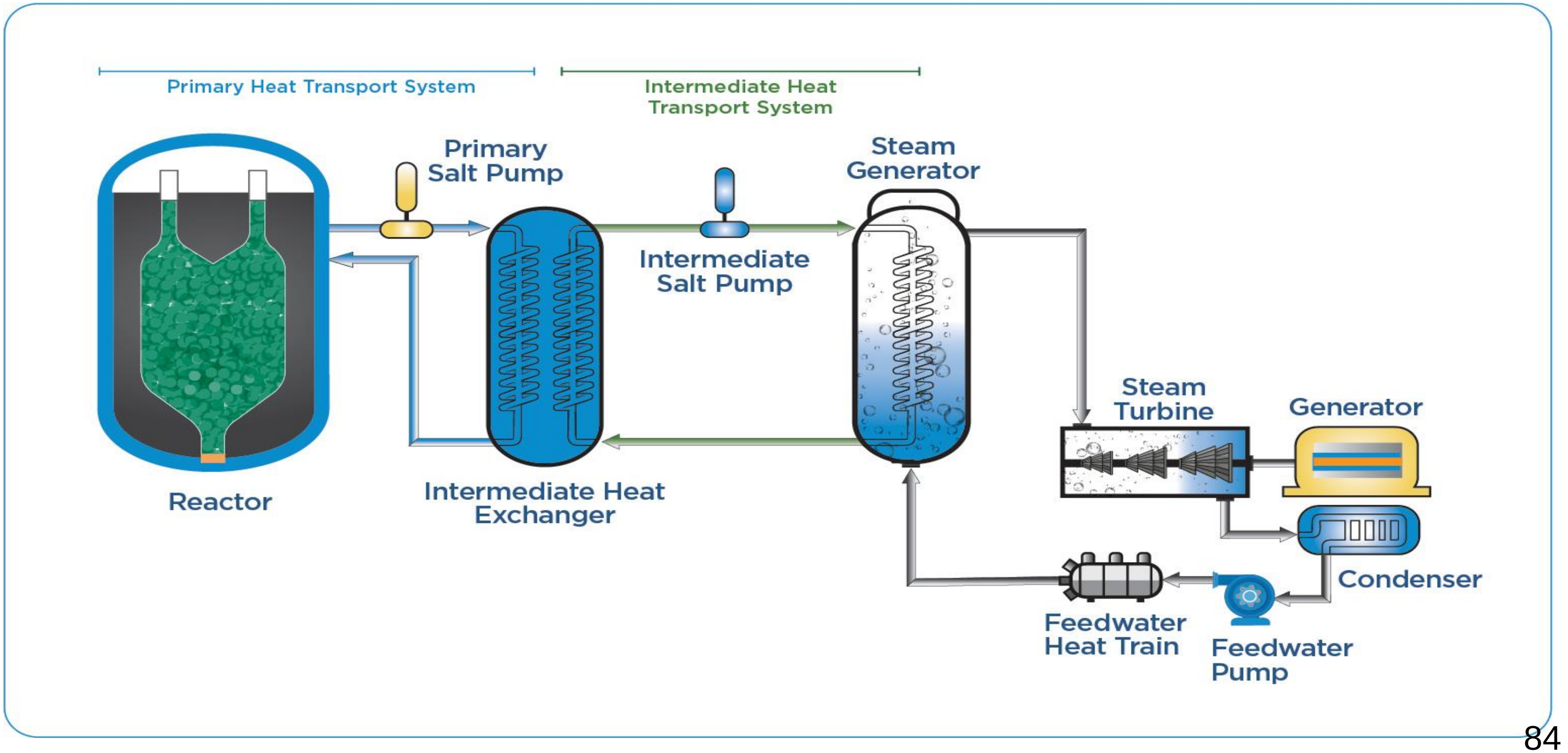
Nella configurazione a celle esagonali le particelle TRISO sono immerse in una matrice di grafite che costituisce le pastiglie prismatiche (figura sottostante, a destra), le quali sono impilate per formare le barre di combustibile. Le barre sono poi inserite in blocchi esagonali di grafite per costituire i gruppi prismatici di combustibile del nocciolo (figura sottostante, a sinistra). Il controllo della reattività avviene con barre assorbenti che vengono calate in appositi spazi presenti nei gruppi prismatici.



Gruppi prismatici di combustibile (a sinistra) e pastiglie di combustibile (destra).

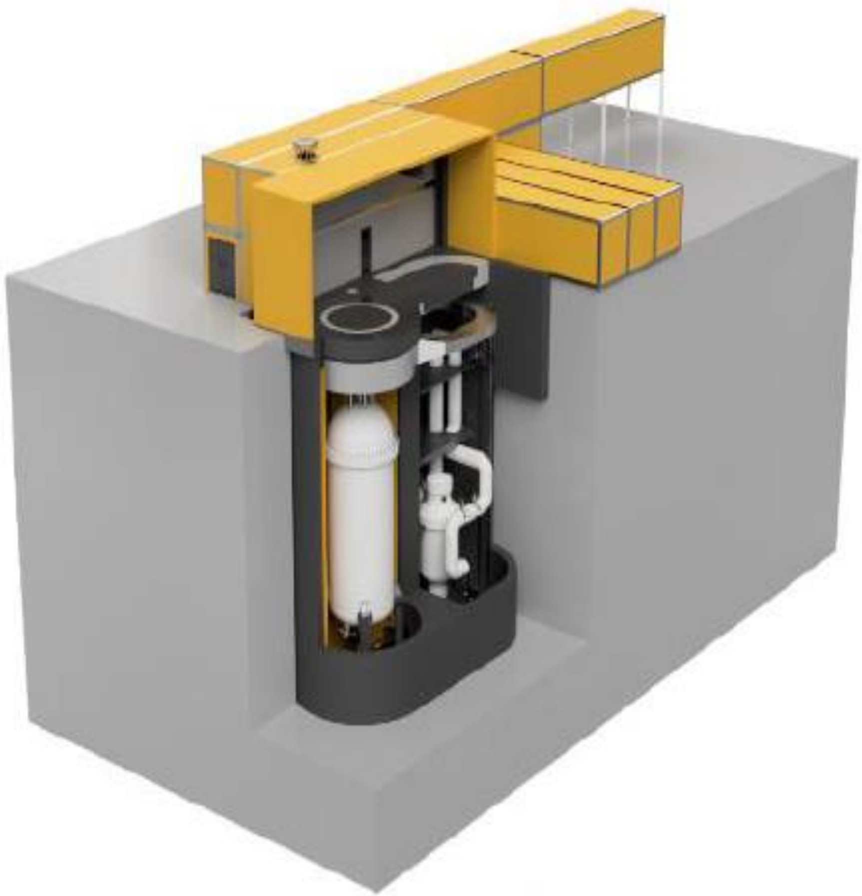
Da: «Impianti nucleari di piccola potenza per la cogenerazione - Produzione di Idrogeno e Teleriscaldamento» Tesi di Lorenzo Labardi – Sapienza Università di Roma - A.A. 2019-2020.

The **Kairos Power FHR (KP-FHR)** is a novel advanced reactor technology that leverages **TRISO fuel in pebble form** combined with a **low-pressure fluoride salt coolant**. The technology uses an efficient and flexible steam cycle to convert heat from fission into electricity and to complement



From: https://kairospower.com/technology/

Il Micro Modular Reactor della ULTRA SAFE NUCLEAR



USNC's MMR design (Image: USNC)

From: https://usnc.com/MMR.html

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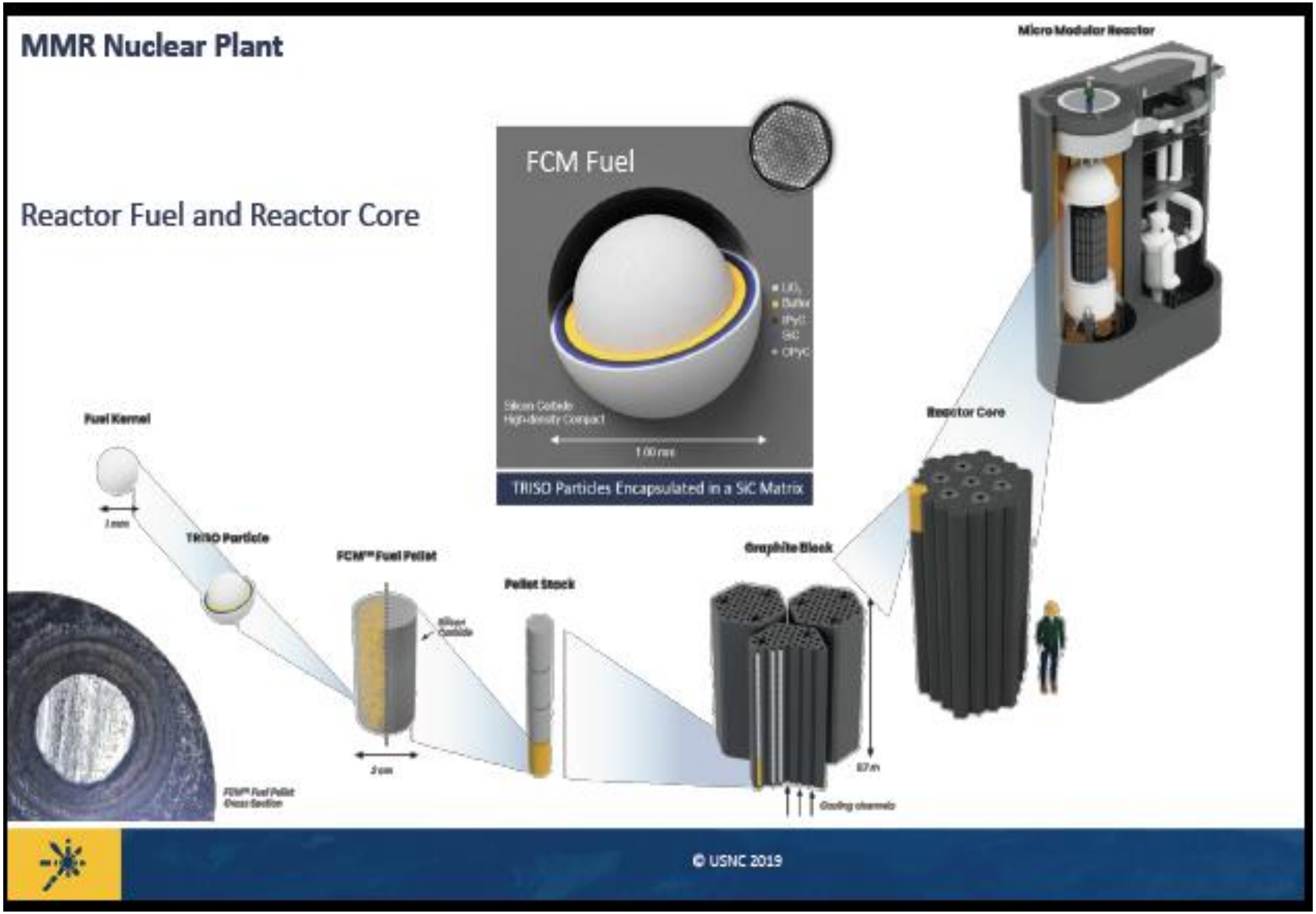

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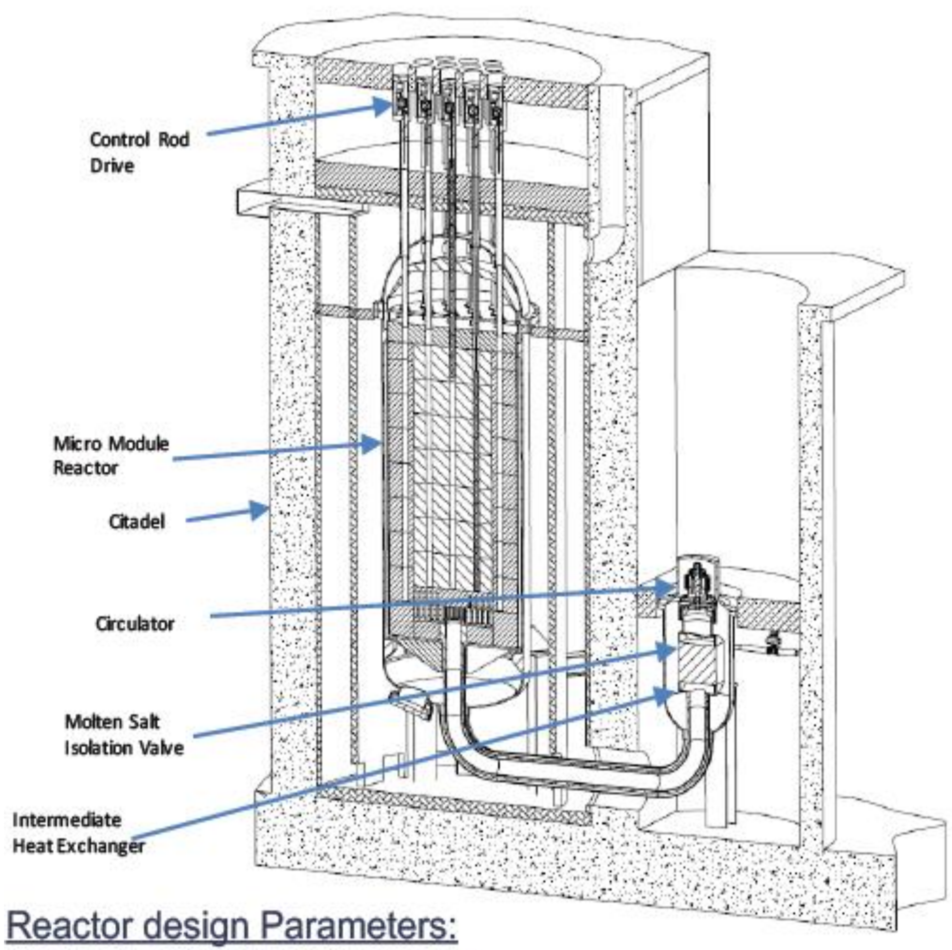
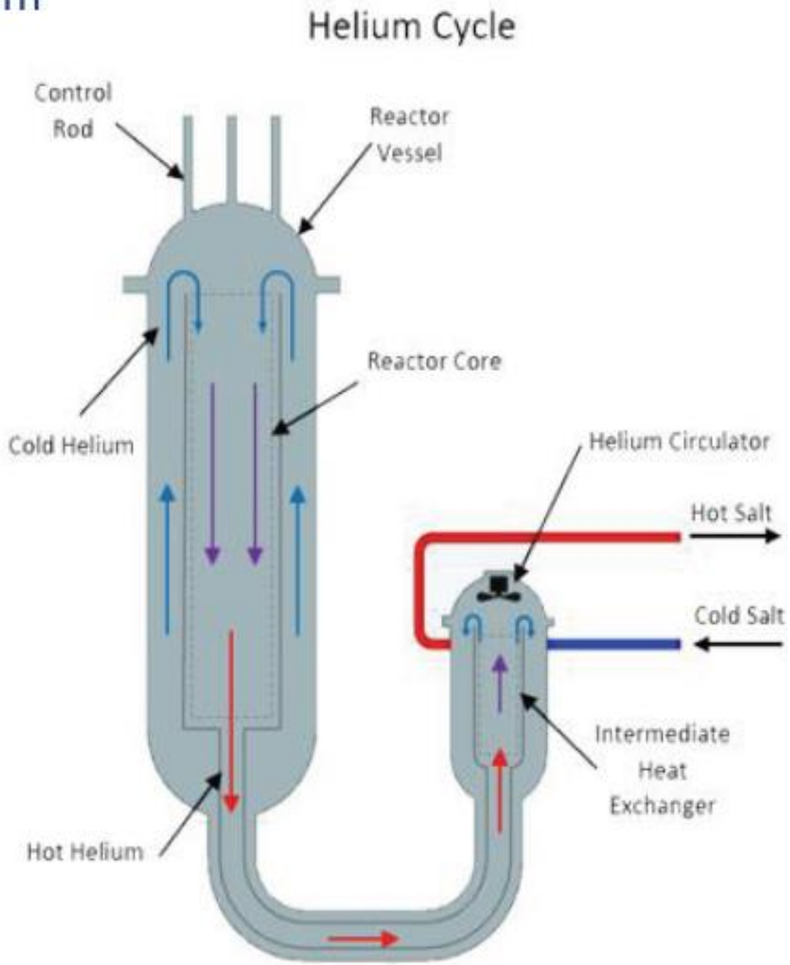
MMR Nuclear Plant: Nuclear Heat Supply System





Reactor design Parameters:
15 MWth, 9-13% enriched UO_2

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MICRO MODULAR REACTOR™

The MMR™ system uses FCM™ fuel. Tiny grains of uranium are clad in several layers of silicon carbide that prevent any release of radioactive gases. The fuel is safe under all operating and accident conditions.

The MMR™ Nuclear Reactor is only fuelled once in its lifetime. There is no refuelling required or spare fuel on site.

The MMR™ reactor is a walk-away, safe-power reactor. In the case of an accident, the MMR™ reactor cannot melt down as any heat dissipates passively into the environment.

The MMR™ plant is small and modular. The modules, which are built on an assembly line, are easily installed at the user site. The MMR™ system is scalable from 5 to 50MW.

The MMR™ plant is simple to operate, and flexible in its outputs. The use of molten salt thermal storage allows for significant flexibility in the supply of both electricity and process heat.

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Reactor Core
Predictable Power

The reactor core consists of hexagonal graphite blocks containing stacks of FCM™ fuel pellets. The MMR™ reactor core has a low power density and a high heat capacity resulting in very slow and predictable temperature changes. The MMR™ reactor is fueled once for its lifetime.

Helium Coolant
The Most Benign Cooling Medium Available

Helium gas is the MMR™ reactor's primary coolant. The helium passes through the nuclear core and is heated by the controlled nuclear fission process. The helium then transports the heat away from the core to the Molten Salt System. The MMR™ reactor uses helium as it is an inert gas; a radiologically transparent, single-phase gas with no flashing or boiling possible. Helium does not react chemically with the fuel or reactor core components. It is easy to accurately measure and control the helium pressure in the reactor.

The FCM™ fuel ensures the helium is clean and free of fission products.

Molten Salt Loop
Intermediate Heat Transfer Loop

The MMR™ plant is simple to operate, and flexible in its outputs. The use of molten salt thermal storage allows for significant flexibility in the supply of both electricity and process heat.

Darlington New Nuclear Project is the only site in Canada with an **accepted environmental assessment and site preparation licence. Ontario Power Generation (OPG) last year selected GE Hitachi Nuclear Energy's BWRX-300 SMR.**

Early site work to begin for Canadian SMR

11 March 2022

Share

Early preparation activities are set to begin at the site of Ontario Power Generation's (OPG) future small modular reactor (SMR), following the award of a CAD32 million contract for the first phase of site preparation and support infrastructure for the Darlington New Nuclear Project.

The site for the SMR is next to the existing Darlington nuclear power plant (Image: OPG)

From: https://www.world-nuclear-news.org/Articles/Early-site-work-to-begin-for-Canadian-SMR

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The infrastructure work covered by the CAD32 million (USD25 million) contract awarded to Ontario multi-trade fabricator and constructor ES Fox includes bringing services such as water, electrical power, information technology and roads to the site, which is **adjacent to OPG's existing Darlington nuclear power plant**.

The **Darlington New Nuclear Project** is the only site in Canada with an accepted environmental assessment and site preparation licence. **OPG last year selected GE Hitachi Nuclear Energy's BWRX-300 SMR** for the site, where it says **Canada's first commercial, grid-scale, SMR could be completed as soon as 2028**.

"This early work sets the stage **for deployment of the type of clean, safe new electricity generation Ontario needs as demand begins to rise due to electrification**," OPG President and CEO Ken Hartwick said.

"The world is watching Ontario when it comes to SMRs," Ontario Minister of Energy Todd Smith said. "I look forward to seeing the progress made by ES Fox and OPG as we prepare to deploy Canada's first grid-scale SMR. **This project will create good jobs and clean energy while cementing our reputation as a global hub for nuclear technology and SMR expertise."**

Researched and written by World Nuclear News

BWRX-300

*One of the most economical SMR designs available**

BWRX300

The **BWRX-300** is designed to provide **clean, flexible baseload electricity generation** that is competitively priced and has the life cycle costs of typical natural gas combined cycle plants **targeting $2,250/kW for NOAK (nth of a kind) implementations**. **The tenth evolution of the Boiling Water Reactor (BWR),** the **BWRX-300** represents **the simplest, yet most innovative BWR design since GE began developing nuclear reactors in 1955**. The result is a dramatic reduction in scale and complexity compared to large reactors, as well as other SMR designs. **BWRX-300** is projected to have **up to 60% less capital cost per MW** when compared with other typical water-cooled SMR and large nuclear designs in the market. The **BWRX-300** is designed for significant **reductions in operating staff, maintenance cost, and security requirements**.

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The key **BWRX-300** innovation is the **elimination of large Loss-of-Coolant Accidents (LOCAs).**

This innovation enables **simpler passive safety systems and a more compact reactor building** compared to prior Light Water Reactor (LWR) designs.

A strong focus on design-to-cost has resulted in an innovative solution that **limits plant volume, concrete and steel**, while utilizing the ESBWR's design and licensing basis to the fullest extent.

Traditional support system designs are simplified and scaled down from the ESBWR.

The **BWRX-300** utilizes **natural circulation and passive cooling isolation condenser systems from the U.S. NRC-licensed ESBWR**.

Steam condensation and gravity allow the **BWRX-300** to **passively cool itself for seven days** without power or operator action during abnormal events, **including station blackout**. **Indefinite cooling is achieved by the simple action of water addition to the isolation condenser pools.**

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The **reactor pressure vessel and other components can be manufactured in various places outside of the U.S.** offering greater supply chain flexibility and assurance of competitive pricing.

The BWRX-300 can be commercially deployed in ~7 years from project start utilizing modular and open-top construction techniques proven in Japan. The **BWRX-300 power plant is approximately 10% of the size and complexity of a large nuclear project**; thereby, substantially reducing project risk and total capital cost requirements.

Key advantages

- World-class safety
- Designed to be cost-competitive with gas
- Up to 60% capital cost reduction per MW
- Scaled from the licensed ESBWR design
- Mitigates large LOCAs
- 7 days of passive standby cooling
- Utilizes common construction techniques
- Requires only limited on-site staff and security

ECONOMY & TECH / SCIENCE

Japan Leads Race in Development of High-Temperature Gas Reactors, but China is Catching Up

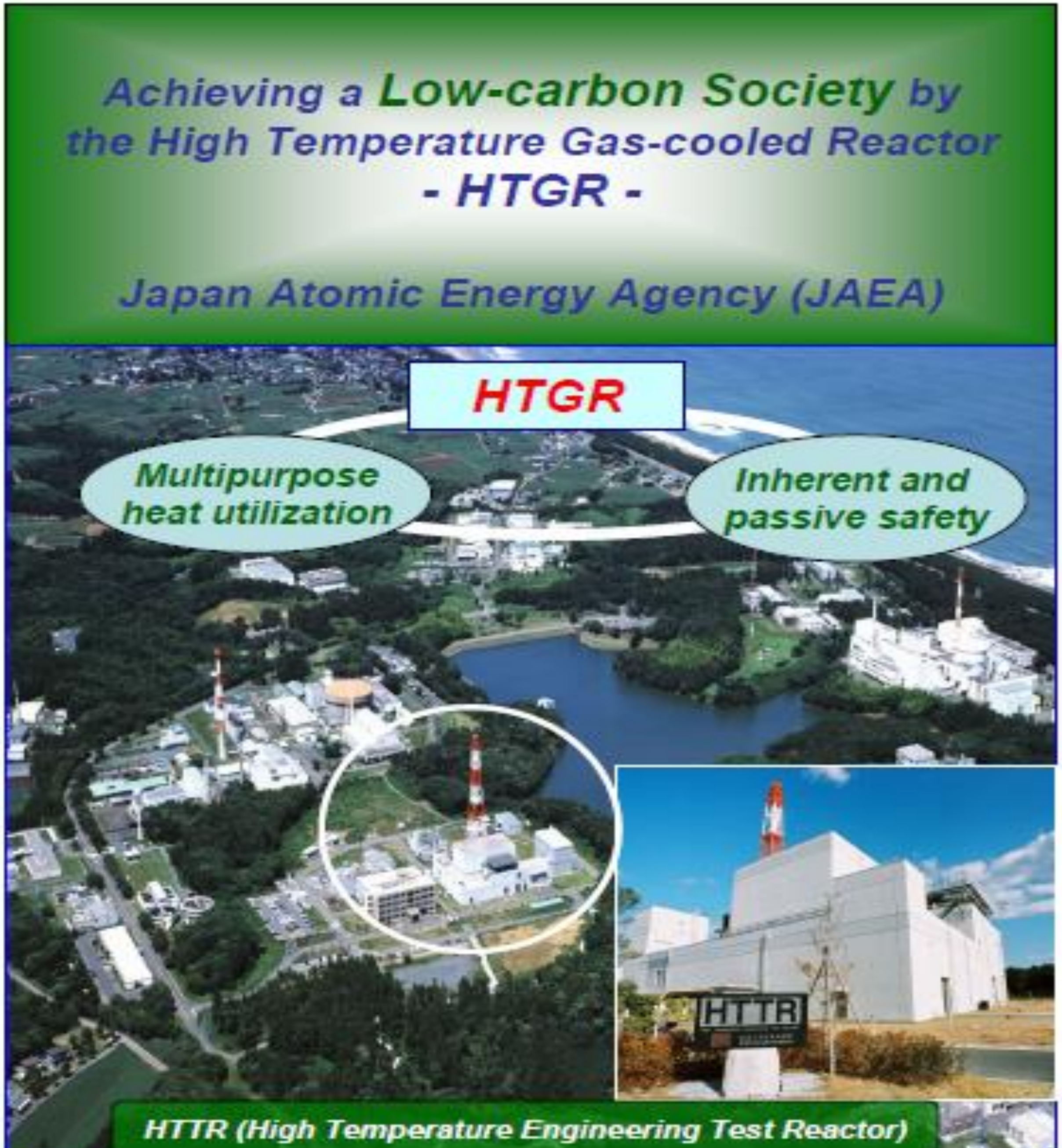
Shohei Nagatsuji April 30, 2020 7:51 pm

(Click here to read this article in Japanese.)

950 degrees, best performing HTGR, china, China HTR-10, Environment, Fukushima, German technology, high temperature gas reactors, high temperature test reactor, HTGR, HTTR, Japan Atomic Energy Agency, Japan Basic Energy Plan, nuclear power, poland, Shandong Province, Shidao Bay, Shohei Nagatsuji, Tsinghua University

Interessante è il fatto che anche **il Giappone stia riattivando la filiera degli HTGR**, riavviando un suo antico prototipo di questo tipo, lo **HTTR**.

Molti altri Paesi ne sono interessati, come la **Polonia**, che, oltre ad annunciare un classico programma nucleare fino ai 9 GWe al 2040, intende **usare gli HTGR per produrre idrogeno**.


Achieving a Low-carbon Society by
the High Temperature Gas-cooled Reactor
- HTGR -
Japan Atomic Energy Agency (JAEA)
HTGR
Multipurpose heat utilization
Inherent and passive safety
HTTR
HTTR (High Temperature Engineering Test Reactor)

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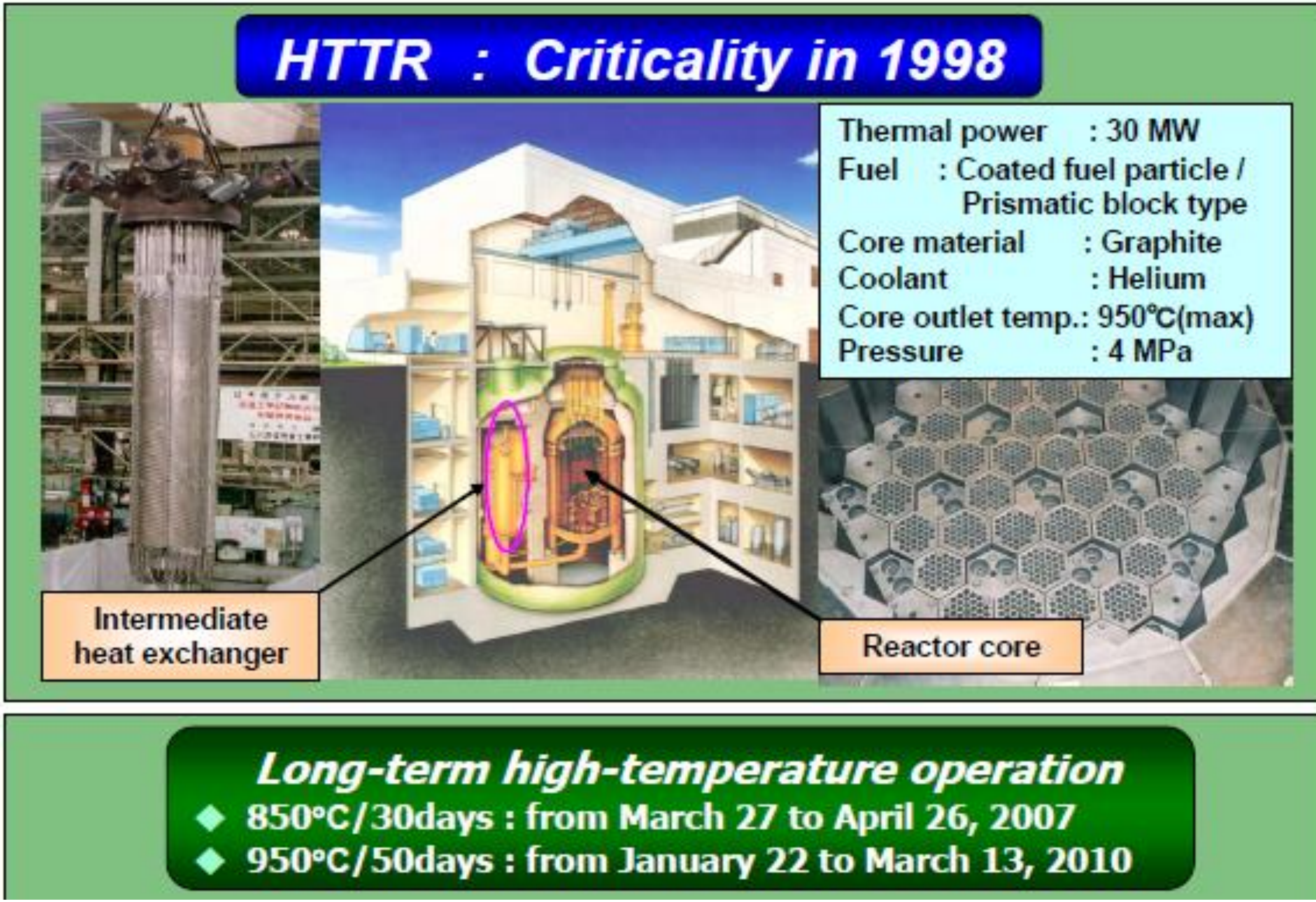

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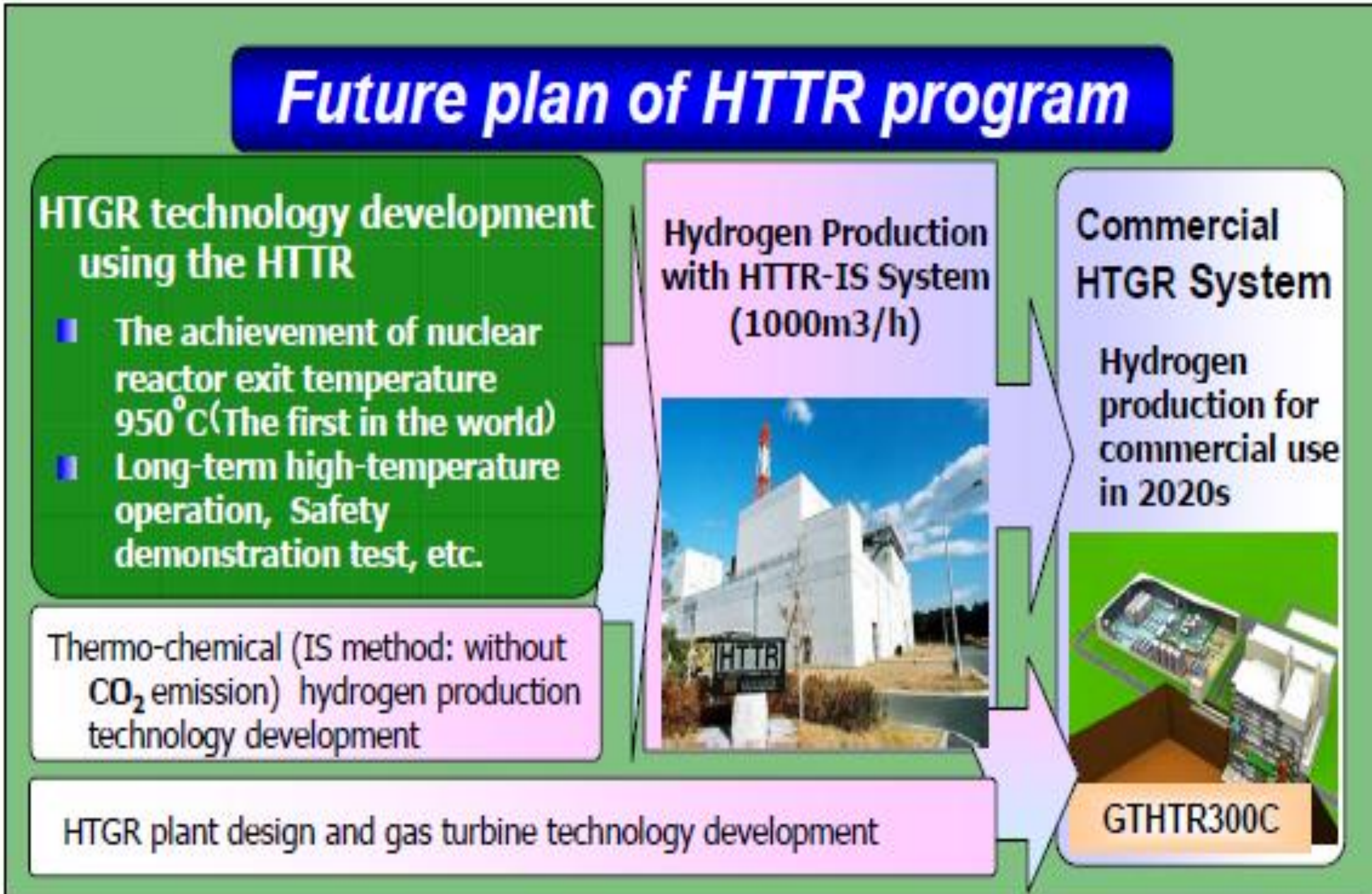
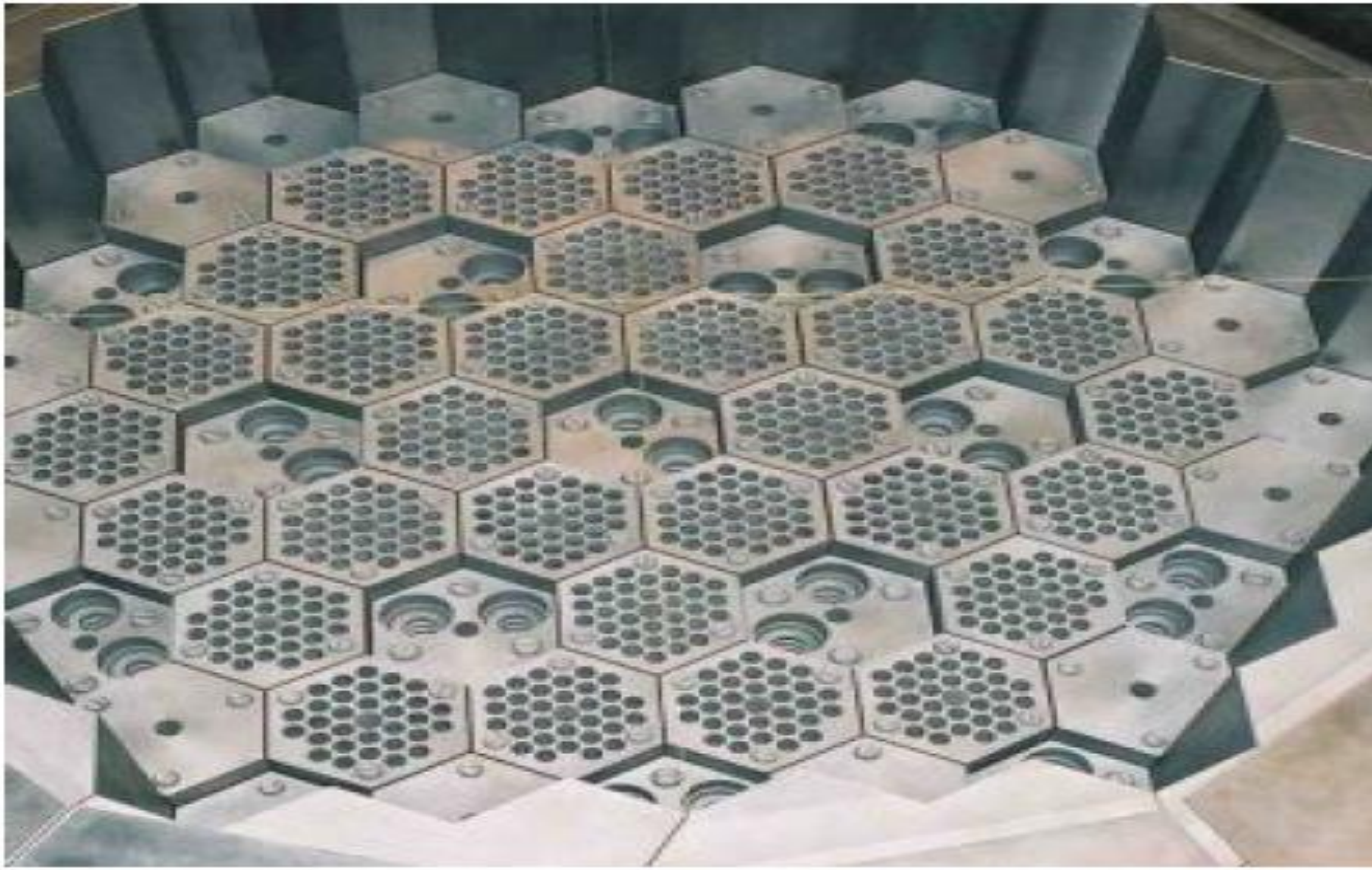


Future plan of HTTR program
HTGR technology development using the HTTR
The achievement of nuclear reactor exit temperature 950°C (The first in the world)
Long-term high-temperature operation, Safety demonstration test, etc.
Thermo-chemical (IS method: without CO2 emission) hydrogen production technology development
HTGR plant design and gas turbine technology development
Hydrogen Production with HTTR-IS System (1000m3/h)
HTTR
Commercial HTGR System
Hydrogen production for commercial use in 2020s
GTHTR300C



Japan's High Temperature Gas Reactor (HTGR)

Picture Courtesy of Japan Nuclear Agency: Core of a HTTR About 3 Meters Wide Comprised of Hexagonal Blocks, Very Different from Classic Light Water Nuclear Reactors

From: https://japan-forward.com/japan-leads-race-in-development-of-high-temperature-gas-reactors-but-china-is-catching-up/

JAPAN Forward

POLITICS & SECURITY EDITOR'S PICK ECONOMY & TECH CULTURE SPORTS SPECIAL REPORTS PO

ECONOMY & TECH

EDITORIAL | With New Nuclear Power Proven Safe, Japan Must Stay Ahead in Technology

The high-temperature gas-cooled reactor would be the ultimate decarbonized power source. It would produce green hydrogen while generating electricity.

Published 2 months ago on February 16, 2022
By **Editorial Board, The Sankei Shimbun**

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The results of **international joint testing have proven the safety of the high-temperature gas-cooled reactor (HTGR).**

Testing conducted by the Japan Atomic Energy Agency (JAEA) on January 28 on the high-temperature test reactor (HTTR) in Oarai, Ibaraki Prefecture (thermal output of 30,000 kW), **proved that it would not melt down even in the event of a total power failure.**

The experiment was conducted under harsh conditions corresponding to **a total loss of power supply and included halting the circulation of coolant and helium gas**.

The HTTR's response was unfaltering. With only the built-in safety features that HTGRs are equipped with, **the HTTR reactor shut down automatically without using control rods, and natural cooling of the core proceeded**.

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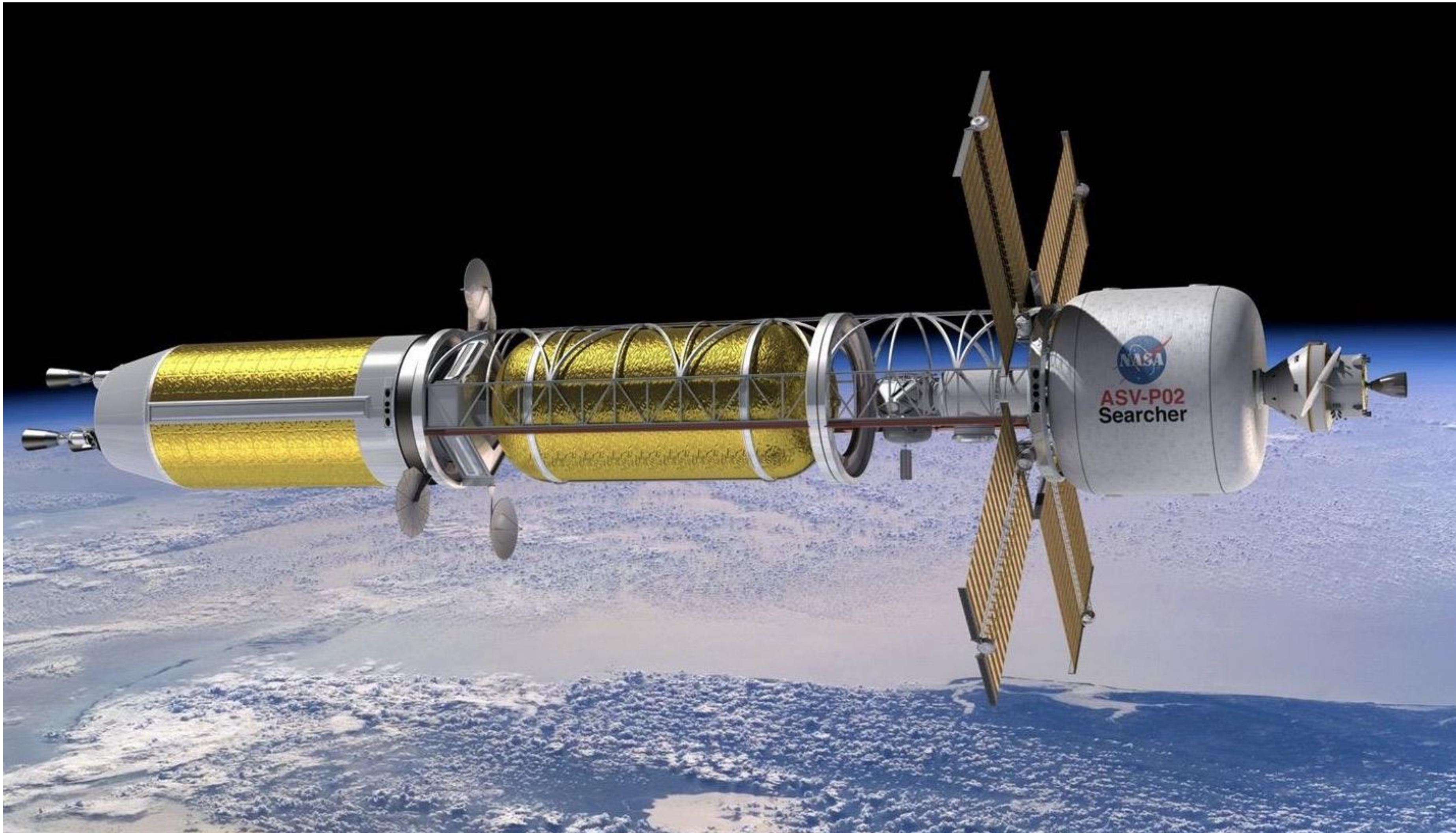
In 2022, JAEA will begin designing **hydrogen production equipment that will use the near-1,000 degrees Celsius high temperature of the HTTR**. The plan is to **first produce hydrogen from natural gas**, and the next step would be to progress to a technology for **mass production of hydrogen that uses only iodine, sulfur, and water, and does not emit any carbon dioxide**.

The HTGR at the practical use stage would be **the ultimate decarbonized power source as it would produce green hydrogen while generating electricity**.

Furthermore, the HTGR is equipped with the **capacity to absorb output fluctuations, which are the fatal weakness of renewable energy sources** like solar power. Therefore, it could help reduce the ratio of thermal power generation. The government should now focus its efforts on accelerating the development of commercial reactors.

Jul 13, 2021 RELEASE 21-091

NASA Announces Nuclear Thermal Propulsion Reactor



(/sites/default/files/thumbnails/image/nuclear_thermal_propulsion-concept.jpeg)

Illustration of a conceptual spacecraft enabled by nuclear thermal propulsion.

Credits: NASA

Related (/multimedia/nasatv/index.html)
NASA TV

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NASA is leading an effort, working with the **Department of Energy** (DOE), to advance **space nuclear technologies**. The government team has selected **three reactor design concept proposals for a nuclear thermal propulsion system**. The reactor is a critical component of a nuclear thermal engine, which would utilize **highassay low-enriched uranium fuel**. The contracts, to be awarded through the DOE's **Idaho National Laboratory** (INL), are each valued at approximately $5 million. They fund the development of various design strategies for the specified performance requirements that could aid in deep space exploration. **Nuclear propulsion** provides **greater propellant efficiency** as compared with chemical rockets. It's a potential technology **for crew and cargo missions to Mars** (https://www.nasa.gov/directorates/spacetech/nuclear-propulsioncould-help-get-humans-to-mars-faster) and science missions to the outer solar system, enabling faster and more robust missions in many cases.

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NASA is also maturing a **fission surface power system for use on the Moon and Mars**. NASA intends to partner with the DOE and INL to release a request for proposals that asks industry for preliminary designs of a **10 kilowatt class system that NASA could demonstrate on the lunar surface**.

Maturing fission surface power **can also help inform nuclear electric propulsion systems**, another candidate propulsion technology **for distant destinations**. NASA's space nuclear technologies portfolio is led and funded by its Space Technology Mission Directorate. The agency's Technology Demonstration Missions program manages the projects to mature affordable, reliable technologies and demonstrate system capabilities to meet power and propulsion needs for future deep space exploration. The program is based at NASA's Marshall Space Flight Center in Huntsville, Alabama.

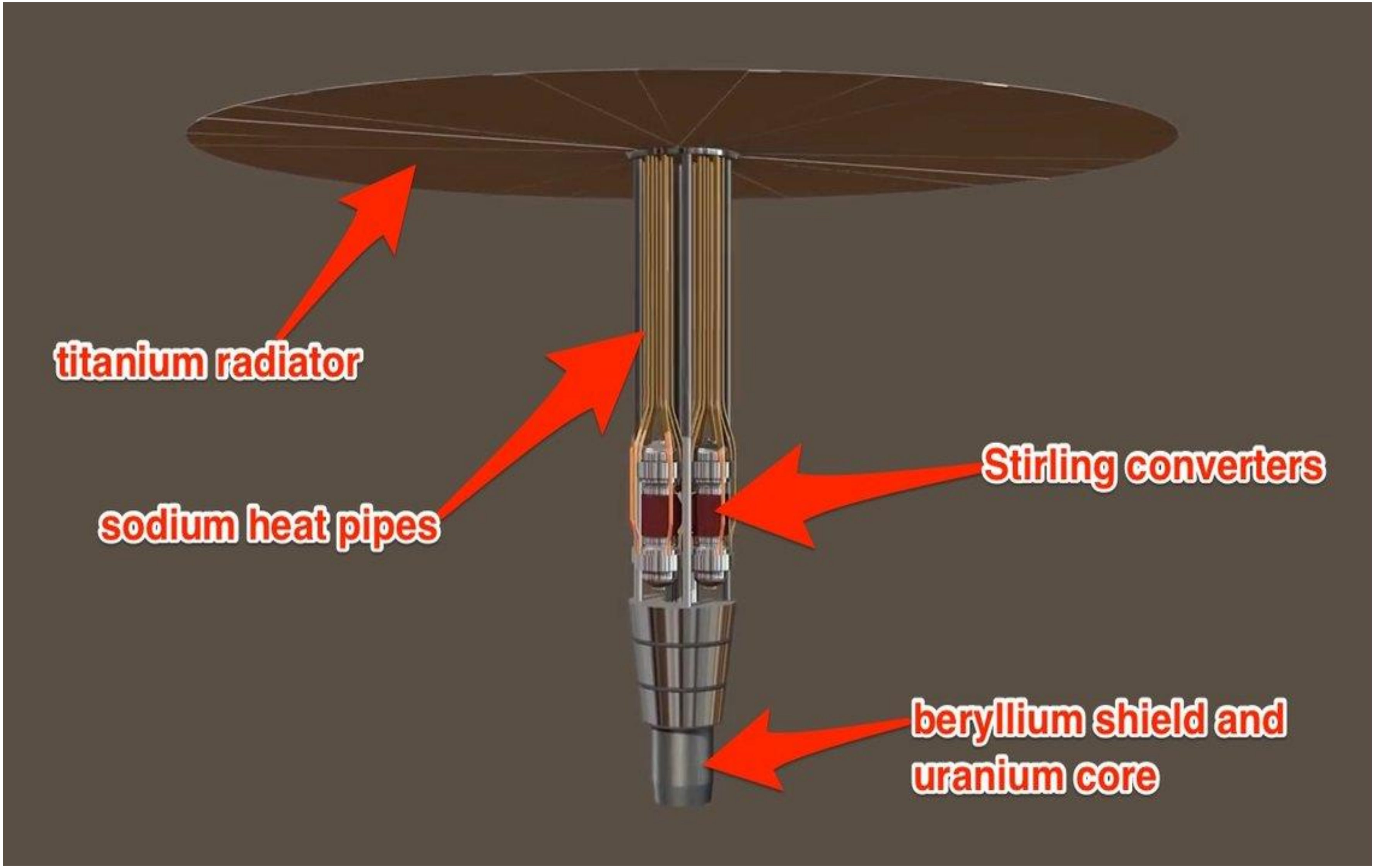
NASA
May 2, 2018
RELEASE 18-031

Demonstration Proves Nuclear Fission System Can Provide Space Exploration Power

NASA and the **Department of Energy's National Nuclear Security Administration (NNSA)** have successfully demonstrated a new nuclear reactor power system that could enable long-duration crewed missions to the Moon, Mars and destinations beyond.

NASA announced the results of the demonstration, called the **Kilopower Reactor Using Stirling Technology** (KRUSTY) experiment, during a news conference Wednesday at its Glenn Research Center in Cleveland. The Kilopower experiment was conducted at the **NNSA's Nevada National Security Site** from **November 2017 through March**.

From: https://www.nasa.gov/press-release/demonstration-proves-nuclear-fission-system-can-provide-space-exploration-power



A labeled diagram of a 10-kilowatt Kilopower nuclear reactor. NASA/YouTube; Business Insider

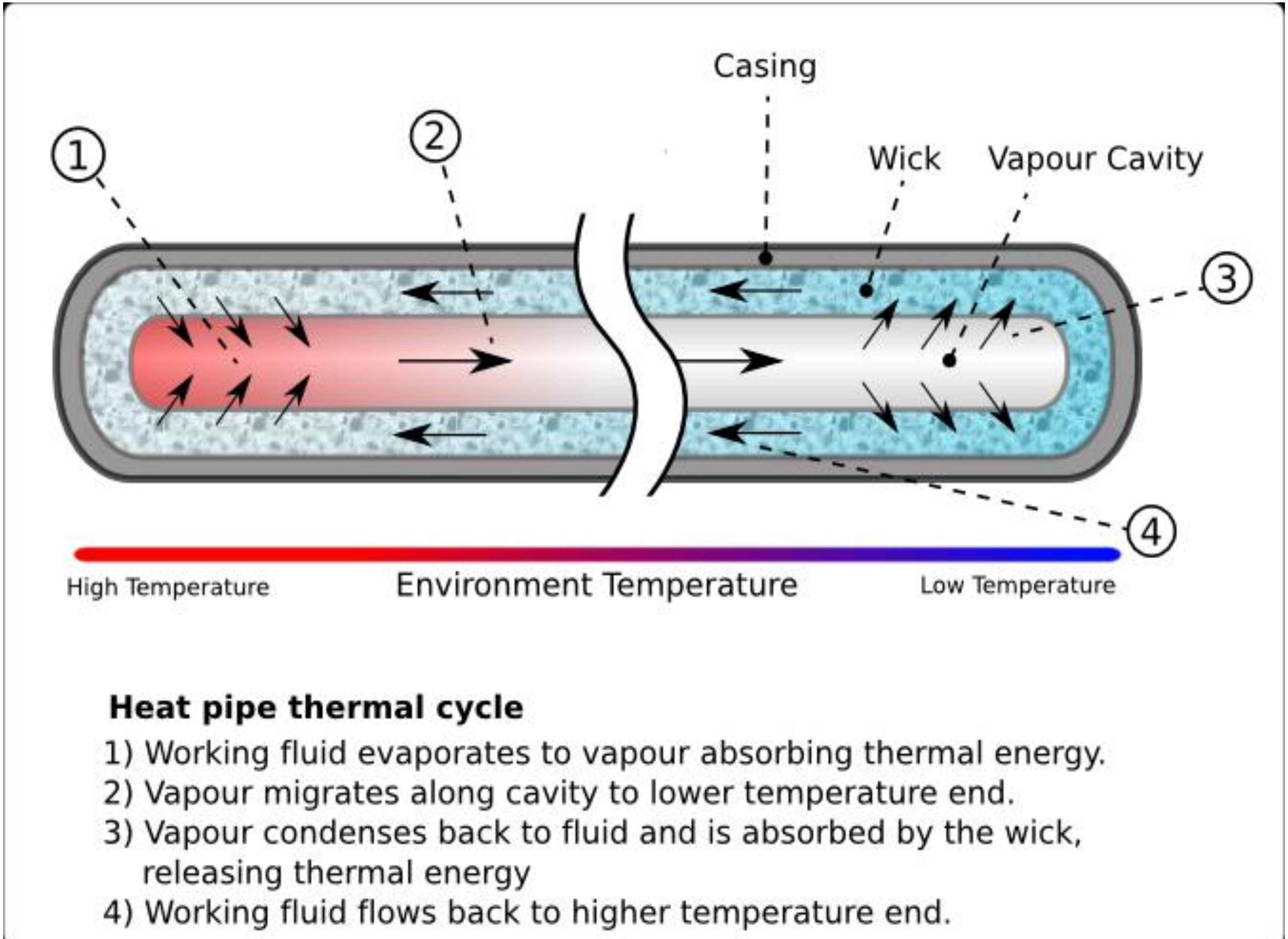
From: http://www.businessinsider.com/nasa-nuclear-reactor-kilopower-how-it-works-2018-5?IR=T

The **Kilopower Reactor Using Stirling Technology** (KRUSTY)

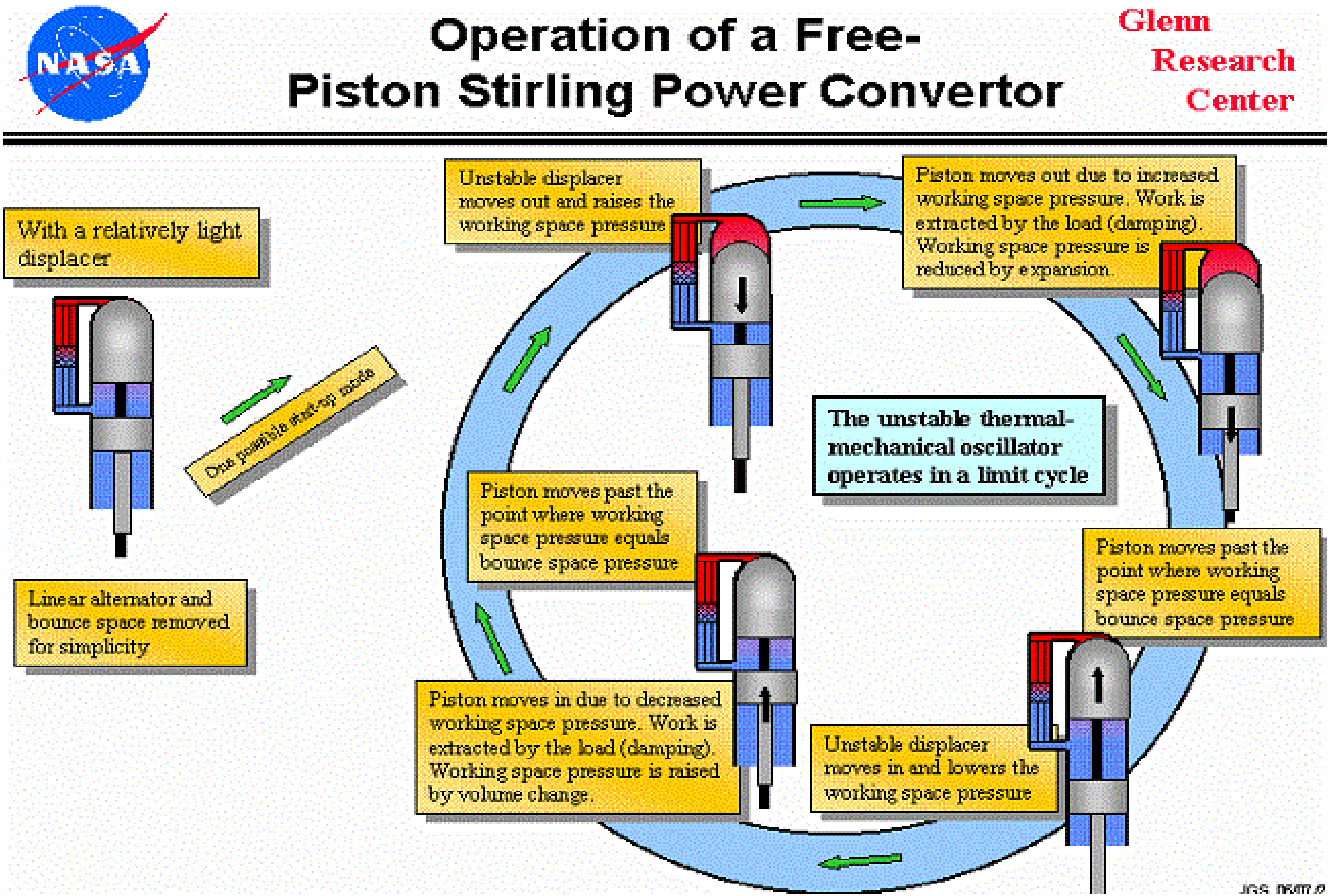
Kilopower is a **small, lightweight fission power system** capable of providing **up to 10 kilowatts** of electrical power continuously **for at least 10 years**. Four Kilopower units would provide enough power to establish an outpost.

The prototype power system uses a **solid, cast uranium-235 reactor core**, about the size of a paper towel roll. **Passive sodium "heat pipes"** transfer reactor heat to high-efficiency "**Stirling engines"**, which convert the heat to electricity.

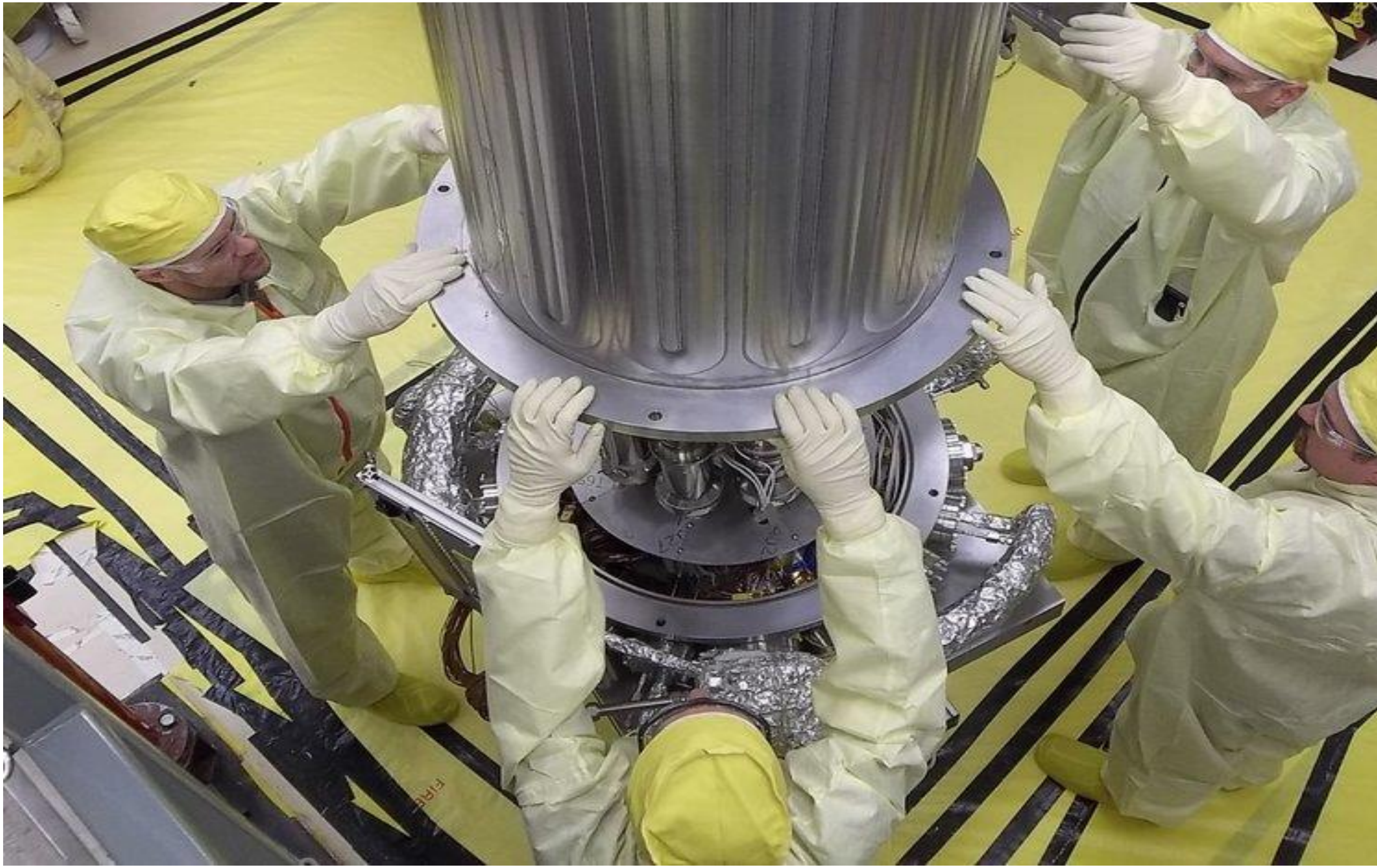
From: https://www.nasa.gov/press-release/demonstration-proves-nuclear-fission-system-can-provide-space-exploration-power



From: https://it.wikipedia.org/wiki/Heat_pipe#/media/File:Heat_Pipe_Mechanism.png

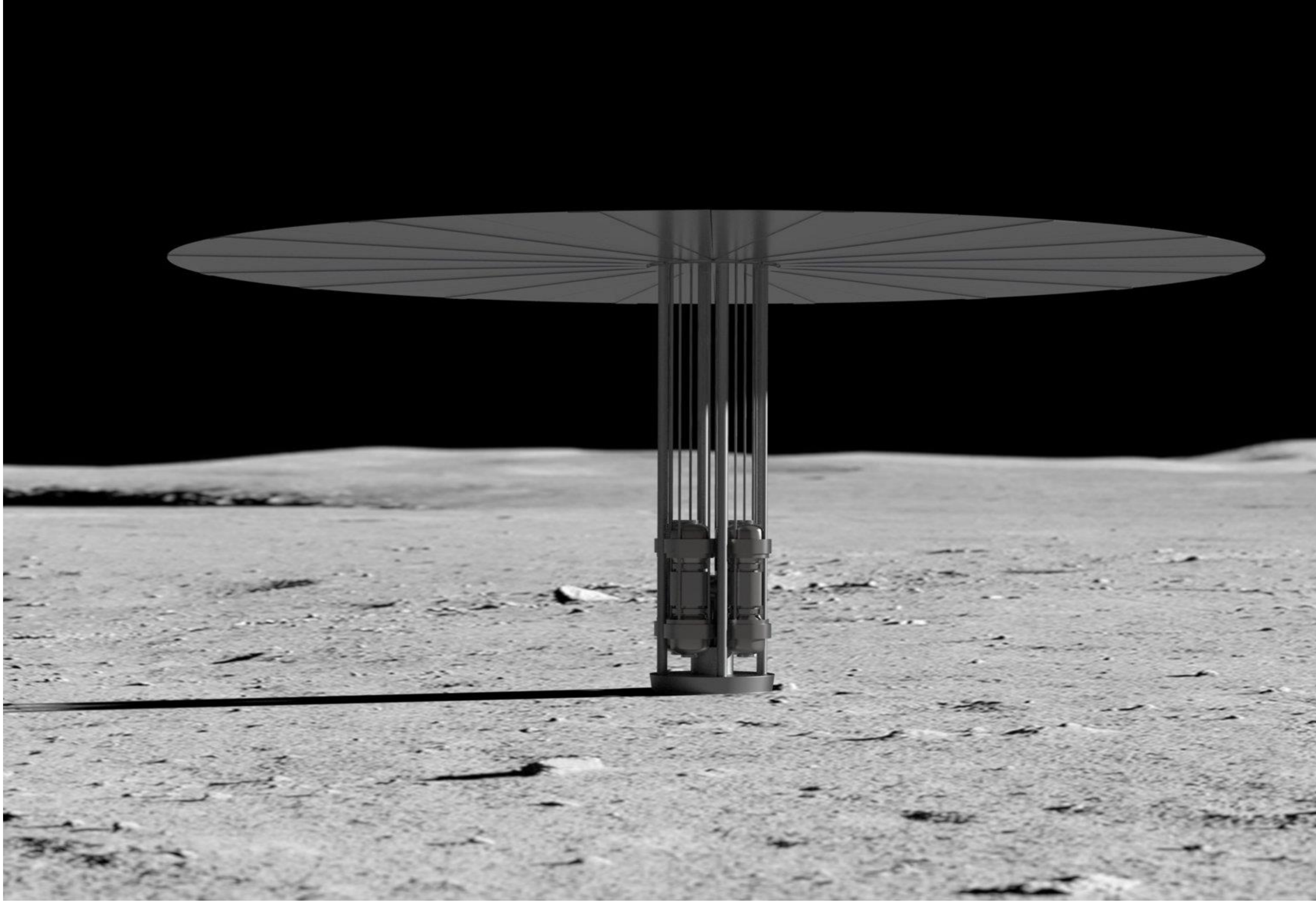


From: https://tec.grc.nasa.gov/rps/advanced-stirling-research/thermal/technology-advancement-project/free-piston-stirling-tutorial/



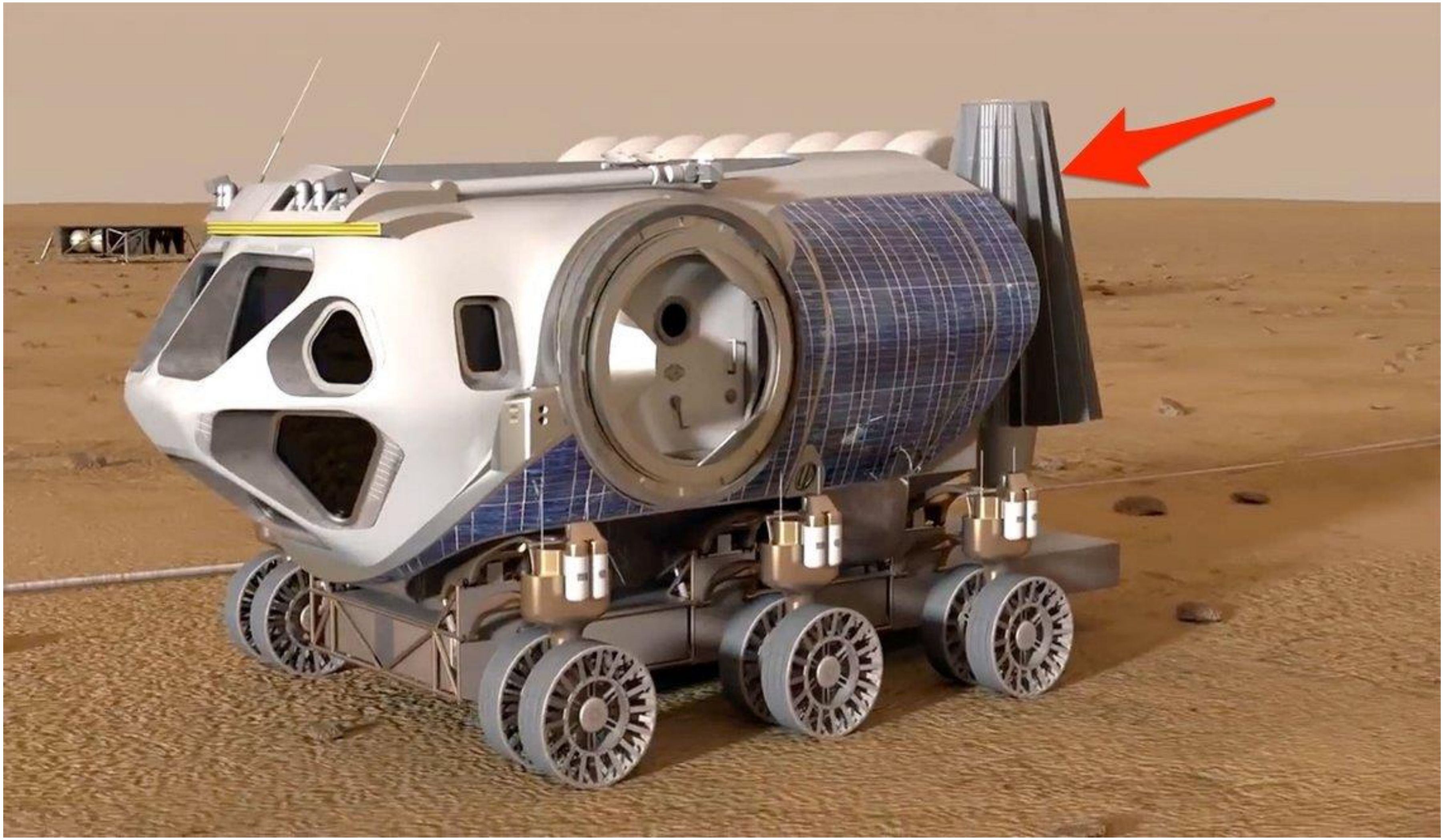
Engineers work on the Kilopower nuclear reactor, a system being designed to power NASA missions. NASA

From: http://www.businessinsider.com/nasa-nuclear-reactor-kilopower-how-it-works-2018-5?IR=T



An artist's rendition of the Kilopower fission reactor and its radiator on the Moon. NASA

From: http://www.businessinsider.com/nasa-nuclear-reactor-kilopower-how-it-works-2018-5?IR=T



An illustration of a folded-up Kilopower nuclear reactor on the back of a Mars roving vehicle.NASA/YouTube; Business Insider

From: http://www.businessinsider.com/nasa-nuclear-reactor-kilopower-how-it-works-2018-5?IR=T

Un very Small Modular Reactor costruito anche in Italia, presso la **Mangiarotti** di Monfalcone (c/o Westinghouse)

Westinghouse launches new SMR effort

After several earlier false starts, including a complete withdrawal in 2014 from efforts to enter the SMR market, **Westinghouse buoyed with a $12.9 million grant from the U.S. Department of Energy**, is making another go of it. The firm said **it will spend $28.9 million to demonstrate the readiness of the technology of its 25 MWe eVinci micro-reactor by 2022**.

From: https://energypost.eu/next-generation-nuclear-25mw-smaller-safer-can-be-sited-anywhere/

Key technical attributes

Here's a short list of key technical details:

- **Transportable** as a reliable energy generator
- **Fully factory built**, fueled and assembled
- Output of **25 MWe electrical**
- **Up to 600ºC process heat** for petro chemical and other industrial uses
- **5- to 10-year life with walkaway inherent safety**
- Target **less than 30 days for onsite installation**
- **Autonomous load management capability**
- **Proliferation resistance** through encapsulation of fuel

From: https://energypost.eu/next-generation-nuclear-25mw-smaller-safer-can-be-sited-anywhere/

eVinci™ Micro Reactor

By Yasir Arafat, and Jurie Van Wyk,
Westinghouse Electric Company LLC.

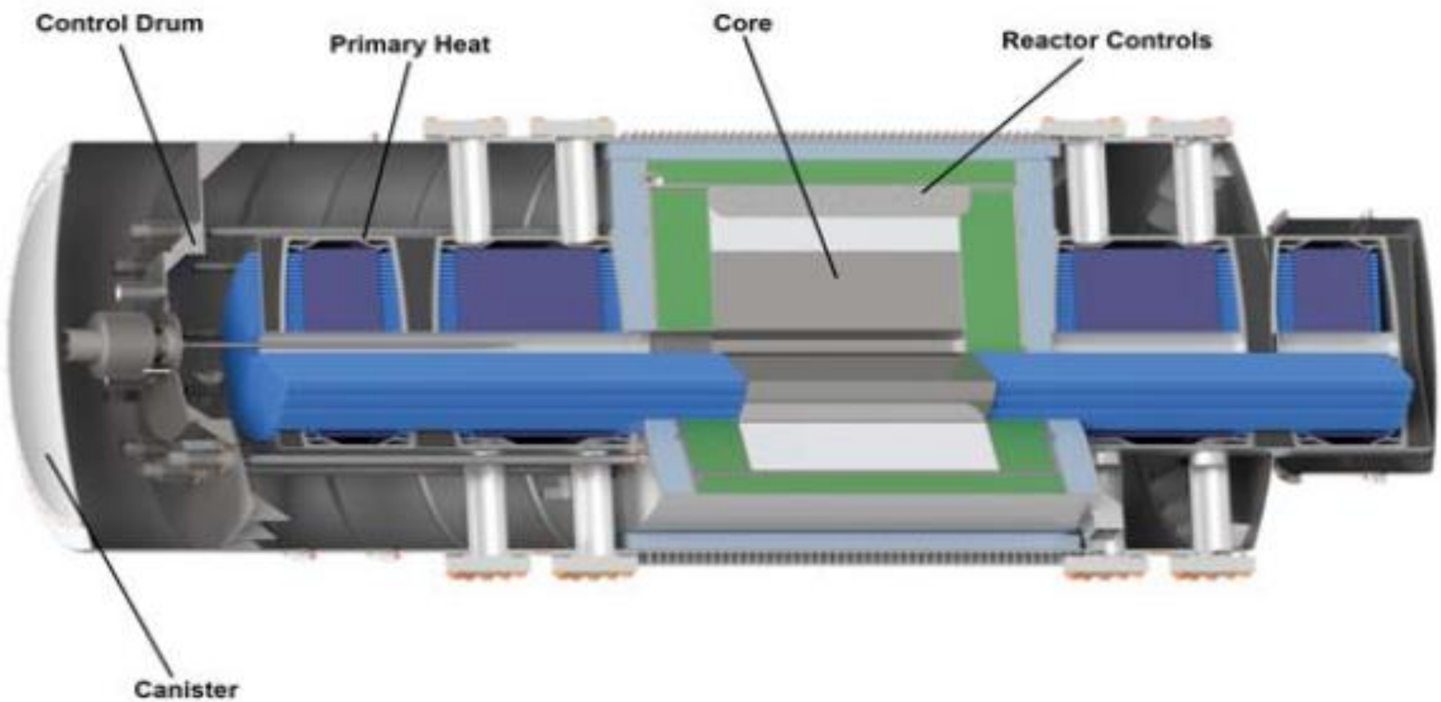
Our Next Disruptive Technology

"Simplicity is the ultimate sophistication." This statement, attributed to Leonardo da Vinci, one of the greatest minds in creative, practical inventions in human history, embodies the guiding principles of the Westinghouse eVinci™ micro reactor design. The eVinci design is based on demonstrated technology that can revolutionize how remote locations access clean, reliable energy.

The eVinci Micro Reactor design leverages the combined forces of LANL's heat pipe technology and Westinghouse's expertise in commercial reactor design, licensing and manufacturing. The resultant product will address some of today's most challenging nuclear safety considerations, such as primary coolant loss, positive reactivity injection due to water entering the core, high-pressure

Wanting to develop the next generation technology to address this global market trend, Westinghouse chose the alkali metal heat pipe technology at the heart of the eVinci micro reactor. Heat pipes enable a simple plant, eliminating the need for a reactor coolant pump, bulk coolant and associated equipment.

eVinci Core Configuration.



eVinci Micro Reactor Overview.

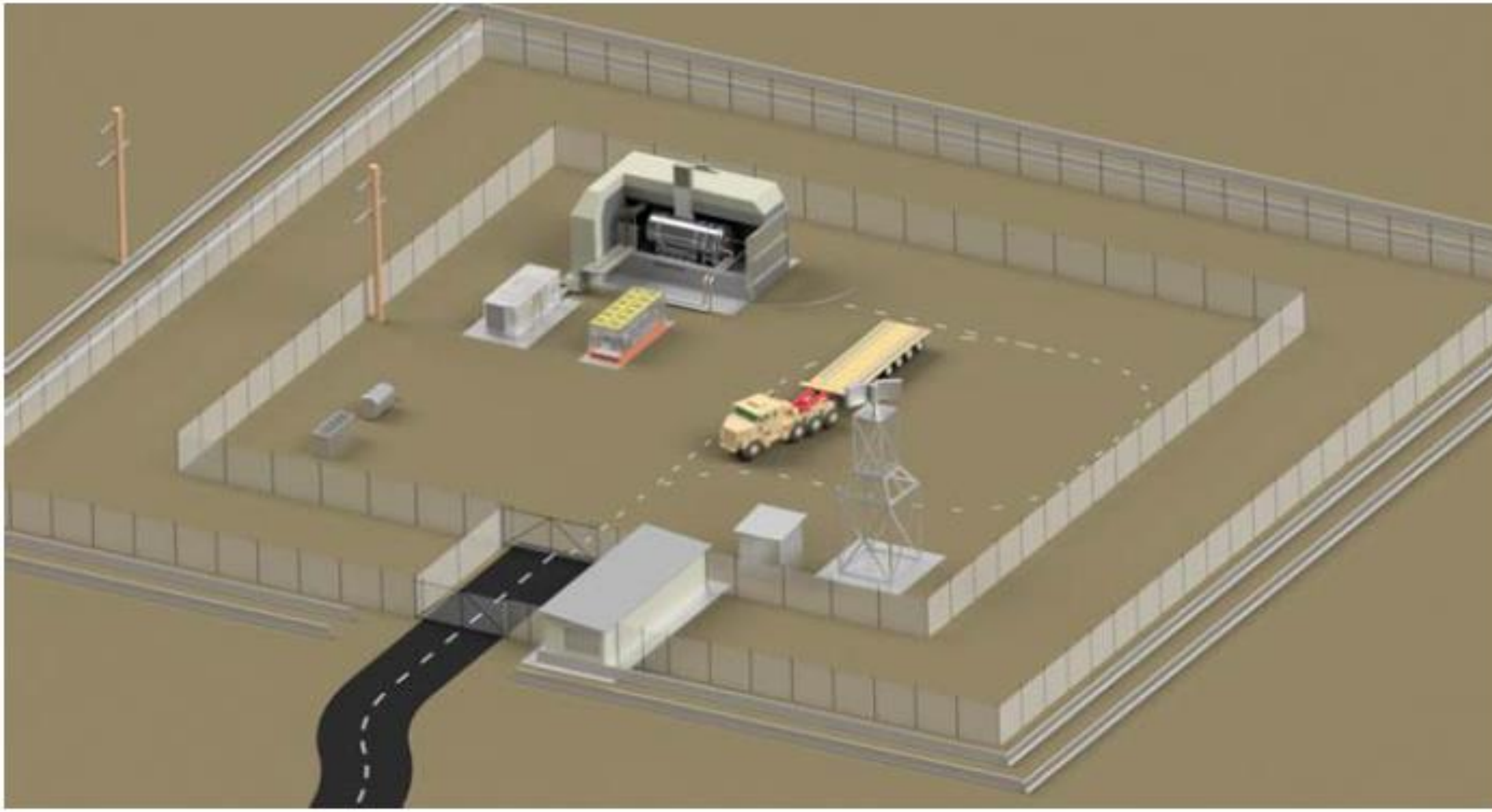
Unlike a high-temperature gas reactor, a heat pipe reactor is not pressurized but can operate at temperatures greater than 650OC. Although heat pipes are passive (naturally driven), they can self-adjust the amount of heat transferred. The self-regulating behavior of the heat pipes and the solid core enables inherent load following. The resultant product can deliver reliable, affordable, flexible and clean energy, with a new level of safety and operability.

NuclearPlantJournal.com Nuclear Plant Journal, March-April 2019

The eVinci design is also planned to deliver combined heat and power with smart load-follow capability via a micro-grid interface subsystem. High-grade heat – up to 600°C – can be used for industrial heating applications such as desalination, hydrogen generation and onsite liquid fuel production. Low-grade heat can be used for district heating or greenhouse applications.

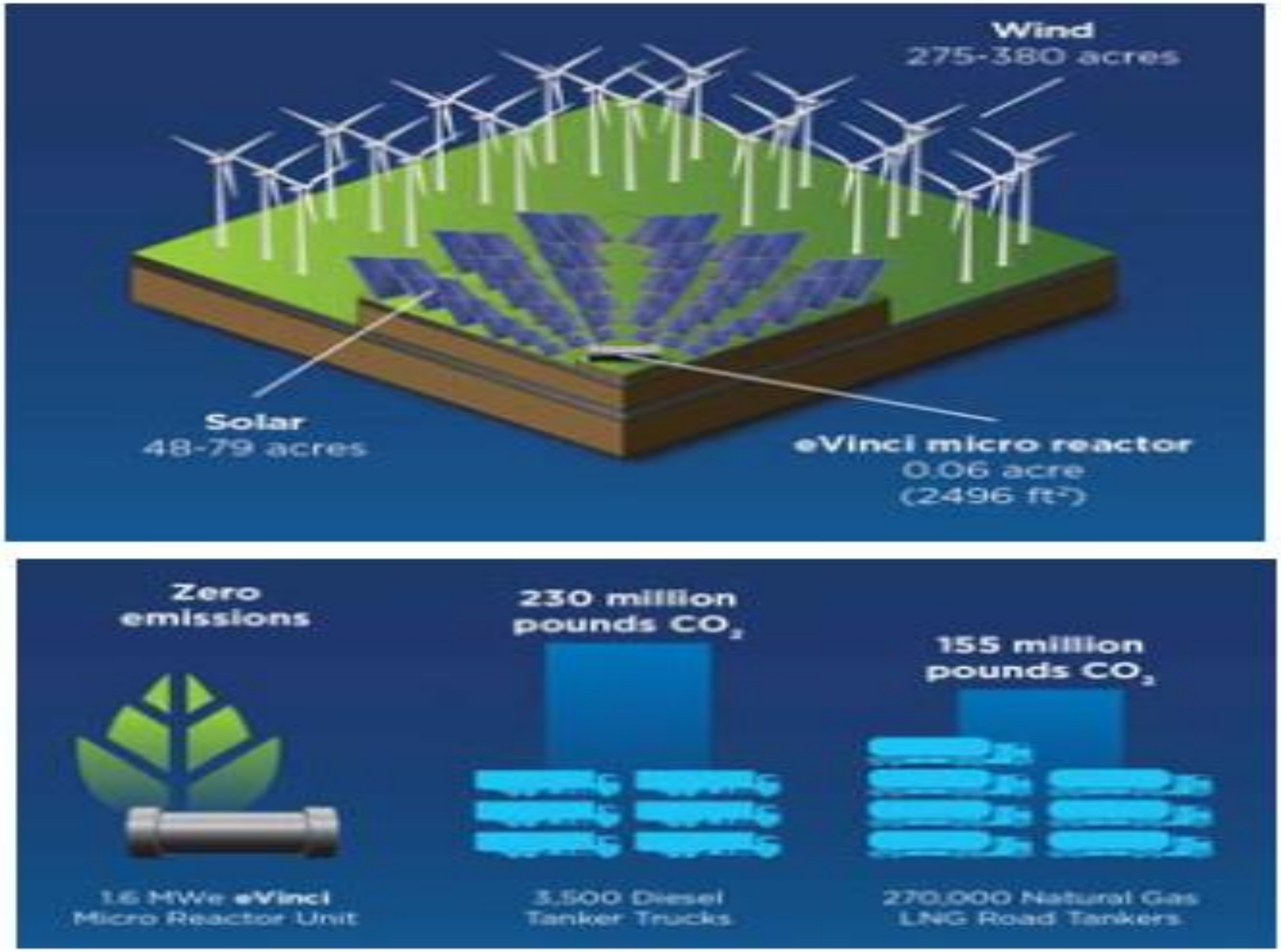
of electric power output goals of specific eVinci micro reactors. Two mature power conversion technology options are being considered to generate electricity. Neither requires cooling water since the final heat rejection is envisioned to be by air and not by water.

NuclearPlantJournal.com Nuclear Plant Journal, March-April 2019



Site plan for single eVinci in a fixed installation– planned for 0.6 acres.

NuclearPlantJournal.com Nuclear Plant Journal, March-April 2019



eVinci compared to other energy sources.

wnn
world nuclear news

US Defense Department awards microreactor contracts

10 March 2020

Share

The US Department of Defense (DOD) has awarded contracts to BWX Technologies Inc, Westinghouse Government Services and X-energy LLC to each begin design work on a mobile nuclear reactor prototype. The engineering design phase of the project will last up to two years, after which one of the three teams may be selected to build and demonstrate a prototype reactor.

Westinghouse will develop the design of a defence version of its eVinci plant (Image: Westinghouse)

The awards are under Project Pele, an initiative under the DOD's Strategic Capabilities Office (SCO) to develop a safe, mobile and advanced nuclear microreactor to support a variety of DOD missions such as generating power for remote operating bases.

Il Sole 24 ORE
Dir. Resp.: Fabio Tamburini
Tiratura: 85917 Diffusione: 138214 Lettori: 740000 (0001581)

Via italiana al nucleare con capitali dei privati

Energia

Nucleare pulito e privato. Newcleo, società dell'imprenditore scienziato Stefano Buono, sul mercato internazionale ha già raccolto 118 milioni. Prototipo in un centro Enea, impianto in Gb. **Bricco** *—a pag. 6*

100

FISICI E INGEGNERI COINVOLTI
Già assunti una quarantina di ingegneri e fisici per il progetto Newcleo, entro fine anno saliranno a cento: «Esiste una grande scuola italiana» spiega l'imprenditore-scienziato Stefano Buono

Via italiana al nucleare con capitali dei privati

Energia. Stefano Buono raccoglie 118 milioni per il reattore pulito: prototipo al centro Enea di Brasimone, a Torino la ricerca, l'impianto in Uk

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31-AGO-2021
da pag. 1-6 /
foglio 3 / 3

La nuova sfida di Mister 3,9 miliardi

Il personaggio

La fondazione della start up biotech AAA e la cessione miliardaria a Novartis

Due numeri: 3,9 (miliardi) e 200 (milioni). Espressi in dollari. Il primo è il prezzo pagato da Novartis nel 2018 per l'Opa totalitaria su Advanced Accelerator Applications, società specializzata in medicina nucleare, in prodotti diagnostici e in terapie nell'oncologia, nella cardiologia e nella neurologia. Il secondo è quanto incassato da Stefano Buono, che ha fondato AAA nel 2002. Buono – in un panorama italiano in cui il venture capital produce più convegni e slide che non progetti industriali solidi e realizzi finanziari cospicui – rappresenta una mosca bianca. Non solo per il track-record, che ha il suo elemento principale nello sviluppo di AAA, nella sua quotazione nel 2015 al Nasdaq e nella acquisizione tre anni dopo da parte di Novartis. Ma anche per la sua fisionomia professionale e culturale: è al contempo uno scienziato e un imprenditore, una identità complessa che gli permette di navigare nell'arcipelago dell'innovazione di rottura, poco frequentato dagli industriali italiani, tradizionalmente – almeno negli ultimi trent'anni – più abituati a navigare nei pur importanti mari dell'innovazione marginale. Buono, classe 1966, dopo il diploma di maturità scientifica al Galileo Ferraris di Torino, sua città, si è iscritto alla facoltà di Fisica. La sua tesi di laurea, realizzata al Cern, era su una nuova architettura dei processori usati per gestire i dati degli esprimenti di fisica. Al Cern rimane come scienziato per dieci anni, lavorando a stretto contatto con Carlo Rubbia. Buono ha sempre avuto la testa da imprenditore, fin da quando – da studente universitario – aveva organizzato il maggior mercato secondario di libri usati per le scuole superiori di Torino. Ma, a differenza di molti altri imprenditori (soprattutto italiani), non ha mai avuto la smania del controllo: non a caso in AAA ha fatto tutti gli aumenti di capitale necessari allo sviluppo della società, diluendo la sua quota finale al 5% e attribuendo ai dipendenti oltre il 20% del capitale. In AAA, dal 2002 sono entrati a più riprese 210 azionisti: 190 privati, 10 istituzionali e 10 imprese. Un modello di public company che, adesso, Buono vuole replicare con Newcleo.

—P.Br.

STEFANO BUONO
Fisico e imprenditore, ha avviato la newco Newcleo per l'energia atomica

News

***new*cleo holds first AGM and launches €300m equity raise to accelerate fuel manufacturing for Generation-IV reactors**

Board of Directors to include senior UK nuclear experts

LONDON, UK, 22 March 2022 – *new*cleo, the clean and safe nuclear technology company developing innovative Generation-IV reactors, held its first AGM yesterday and announced the launch of a new €300 million fundraising round to underpin its strong growth trajectory.

*new*cleo is designing and building lead-cooled fast reactors (LFRs), a new generation of Advanced Modular Reactors (AMRs) that will enhance safety at a competitive cost and have the capability to burn the already existing waste produced by traditional nuclear plants.

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<Most of the **circa 500 commercial nuclear power reactors** operating today produce **hundreds of thousands of tons of depleted uranium**. They also produce **hundreds of tons of plutonium and minor actinides**, all toxic waste that needs to be appropriately disposed of and put into geological repositories, with enormous costs for governments and society. ***new*cleo's LFRs allow these waste materials to be entirely transformed into new fuel to burn for energy production**.

*new*cleo's technology will **hugely reduce the environmental impact of nuclear fission through a very significant decrease in production of radioactive waste**. It enables the **closing of the fuel cycle**; a key requirement of the EU Commission **for the inclusion of nuclear technology within the EU Taxonomy** of environmentally sustainable economic activities. >

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<The company has hired a number of high-calibre, internationally experienced executives to form its leadership team, as well as **almost 100 colleagues largely in roles across its Turin-based scientific team**. It has recently signed **an agreement with ENEA in Italy, for the rapid construction of the world's first non-nuclear, full-scale Generation-IV lead-cooled reactor prototype**. It has established its subsidiary in France and is undertaking a strong recruitment drive for its UK-based team in both business and project focused roles>.

<**Stefano Buono**, *new*cleo founder and CEO, commented: "The importance of creating a cost effective, sustainable, and independent energy source that is completely decarbonised is undisputable. Using our technology, **a 4 GWe fleet of our nuclear reactors could eliminate 15 tons of plutonium every 10 years**, whilst safely generating emissions-free energy. The current stockpile of nuclear waste in UK alone could eliminate the need for mining, enrichment and import of uranium for hundreds of years!>

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<Our reactors are also **completely compatible with a strategy of expanding existing fleets of traditional Water Reactors or Pressurized Water SMRs**, since we can ensure their environmental sustainability by burning their waste.

This significant momentum and the strong interest we are receiving internationally has led us to accelerate our investment plans. This capital increase will enable us to **accelerate the building of our second nuclear prototype, that we aim to start operating within 7 years**, whilst also **creating a manufacturing facility to transform nuclear waste into fuel.”**>

<This significant programme of development activities, which *new*cleo aims to carry out as rapidly as possible, is based on private investments. Given the significant interest expressed by existing and new potential investors since launch, **the company and its Board have agreed to launch a €300 million fundraising round to be executed over the next few months. This comes after newcleo successfully closed a €100 million founding capital round as recently as September 2021**.>

Nuclear vessel 'could be floating charging station for electric cruise ships'

29 April 2022

Share

Norwegian shipbuilder Ulstein has launched the design concept for a replenishment, research and rescue vessel - referred to as *Thor* - that will feature a thorium molten salt reactor. It says the ship could be used as a mobile power/charging station for a new breed of battery-driven cruise ships.

The Thor concept design (Image: Ulstein)

The 149-metre-long vessel features helicopter pads, firefighting equipment, rescue booms, workboats, autonomous surface vehicles and airborne drones, cranes, laboratories and a lecture lounge.

From: https://www.world-nuclear-news.org/Articles/Ulstein-touts-nuclear-concept-for-decarbonising-cr

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<**Molten salt reactors** (MSRs) use **fuel dissolved in a molten fluoride or chloride salt**, which functions as both the fuel (producing the heat) and the coolant (transporting the heat away, and ultimately to the electricity generating equipment). There are a number of different MSR design concepts, and a number of interesting challenges in the commercialisation of many, especially with **thorium**.

To demonstrate the feasibility of *Thor*, Ulstein has also developed the ***Sif* concept, a 100-metre-long, zero-emission expedition cruise ship**. Accommodating up to **80 passengers and 80 crew**, *Sif* will offer silent, zero-emission expedition cruises to **remote areas**, including Arctic and Antarctic waters. The vessel will run **on next-generation batteries, utilising *Thor* to recharge while at sea**.

Ulstein said *Thor*'s charging capacity has been scaled to satisfy the power needs of **four expedition cruise ships simultaneously**. ***Thor* itself would never need to refuel**. As such, *Thor* is intended to provide a blueprint for entirely self-sufficient vessels of the future.>