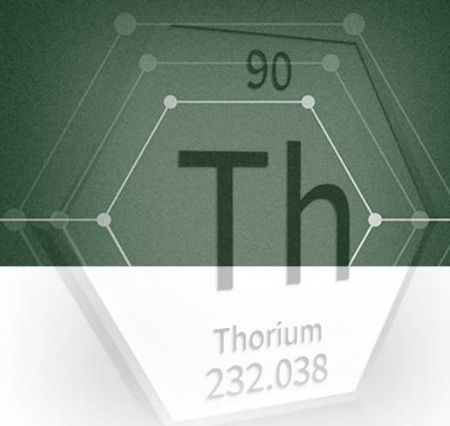
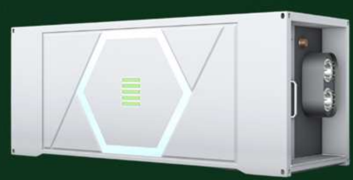
emerald horizon

The Neutron Factory based on CERN Technology





ENERGY STORAGE

ENERGY PRODUCTION

THE GROUNDBREAKING INNOVATIONS & STRONG PARTNERS

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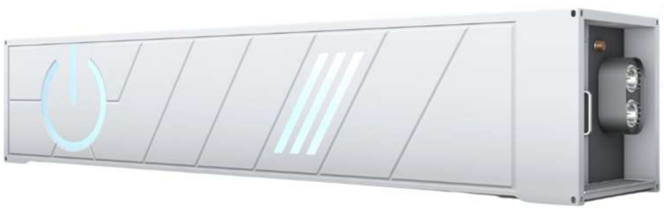

ADVANCED NUCLEAR ENERGY TECH

Accelerator Driven Energy Source

TRL 4.5 / 9)

ADVANCED MOLTEN SALT STORAGE TECH

CALstore

TRL 6.5 / 9

TU Graz · copenhagen atomics · FFG Forschung wirkt. · Jožef Stefan Institute · neutron therapeutics · BERNARD GRUPPE · QBASIS INVEST · Proud member of GREEN TECH CLUSTER · pwc

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Proven Leaders and Scientific Pioneers

Executive Team - Leaders with experience from the World Bank, the IMF, the Austrian National Bank, and PwC.
Scientific Team -Experts in nuclear physics, mechanical engineering, medical technology, and industrial manufacturing.

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The Problem-Risk-Need-Analysis

RISK
Constant requirement of natural resources

RISK
Instabilities due to weak power- grid expansions

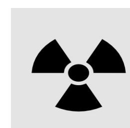
RISK
Deindustrialization

RISK
Popular uprising

RISK
Oil based transportation

RISK
Transuranic nuclear waste

RISK
Critical chain reaction



RISK
Volatile renewables

RISK Loss of critical infrastructure

RISK
Coal based heat production

RISK
Climate change

...all these RISKS could be reduced with ONE solution!

SOLUTION - COMPACT, SAFE AND PROFITABLE

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- No critical chain reaction
- No risk of explosion
- No meltdown risk
- No Plutonium or Uranium 235
- Non-weapons-grade material
- Secure energy supply
- No uncontrolled nuclear waste > 100,000 years
- + USP – No Tl-208 production

- Zero CO2 emission
- Non-volatile energy
- No large powerlines
- High power density
- High profitability with global impact
- Low land-use requirements for systems
- Affordable high temperature heat > hydrogen or electricity
- + "Proof of concept"

ADES
Accelerator Driven Energy Source

FROM ORIGINAL CONCEPT TO COMPACT INNOVATION

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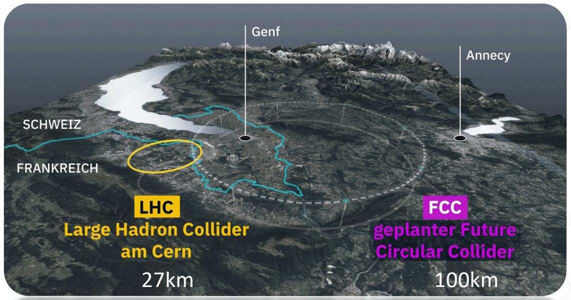
The concept was pioneered by Carlo Rubbia.
While particle accelerators were once too large, today's technology has made them compact and efficient.

Carlo Rubbia, Nobel Prize winner in Physics 1984,
CERN Director and creator of the Energy Amplifier concept



Other Particle Accelerators: Large Size and High Costs

Our Particle Accelerator: Compact and Cost-Efficient
Measuring Only 8 Meters

4 KEY FACTORS – ONE POWERFUL SOLUTION

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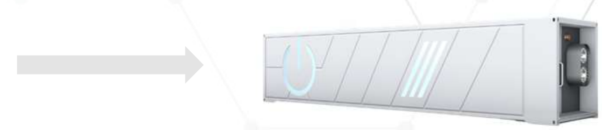

Ideal for regulatory affairs and golbal distribution
(relevant for high scalibility and profitability)

- ☑ No Plutonium or Uranium added
  → no transuranic waste
- ☑ No critical chain reaction needed
  → no risk of explosion

THORIUM ENERGY – 20 YEARS OF POWER WITHOUT REFUELING

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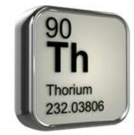
OIL vs. THORIUM (Th)

2.800.000 x  **OIL** = **0,34 x**  

Important: Thorium is a byproduct
3 x more common than Uranium and
300 - 400x more than Uranium-235

Thorium & ADES

OIL energy-eq: Barrel = 2.800.000 pcs. | m = 360.000.000 [kg]
E = 4,4 [TWh]

THORIUM energy-eq: m = 440 [kg] V = 44L ~ 0,3 Barrel
E = 4,4 [TWh]

MULTIPLE USE CASES – BUILT FOR SCALABLE GROWTH

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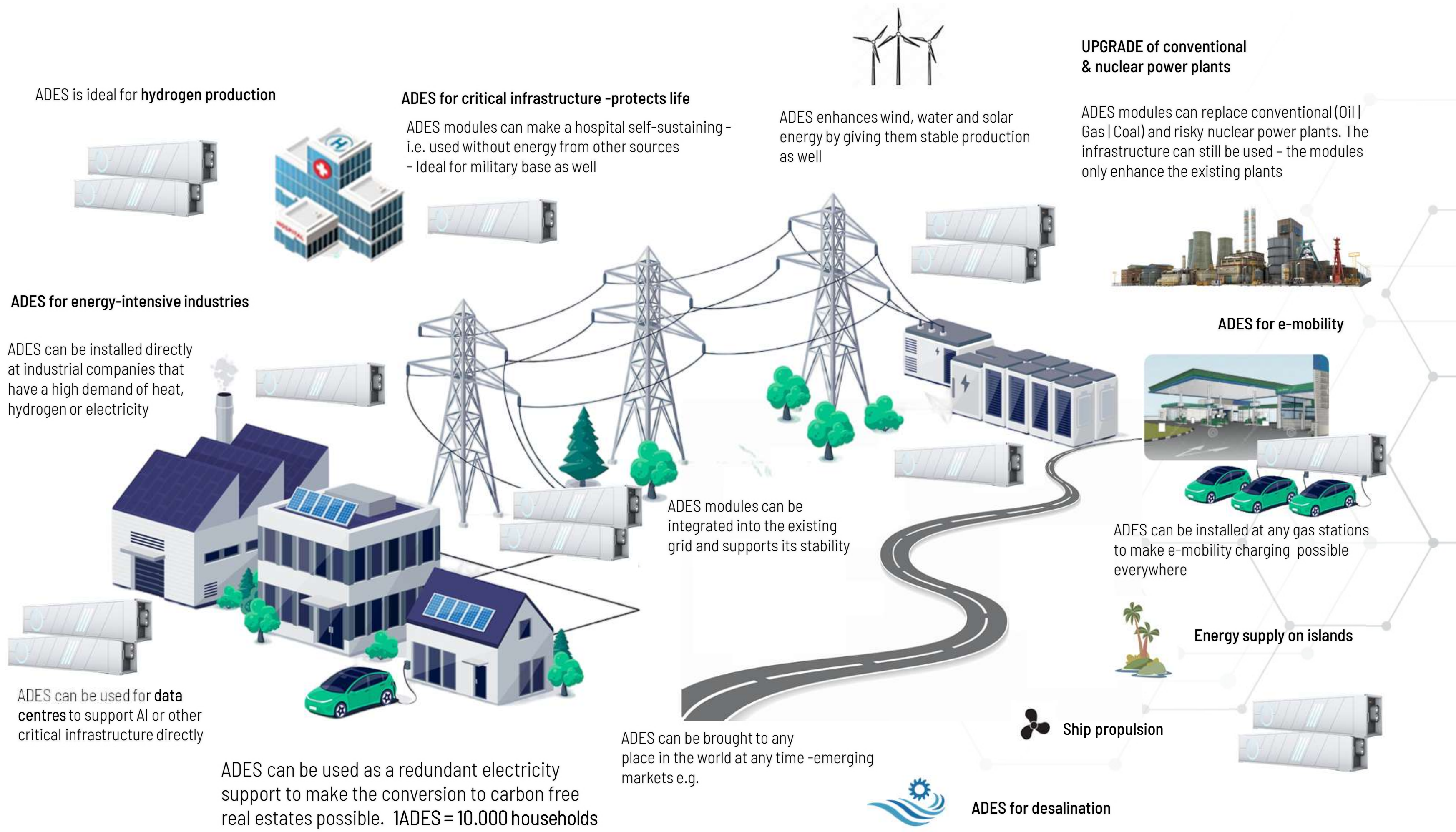

MODULAR & AI-DRIVEN – DESIGNED FOR EVERY USER

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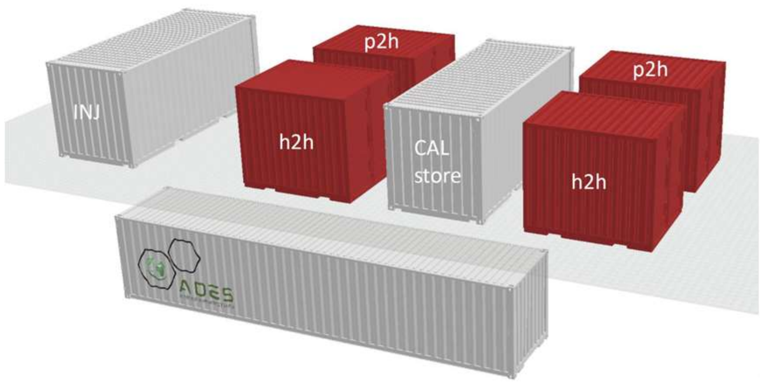
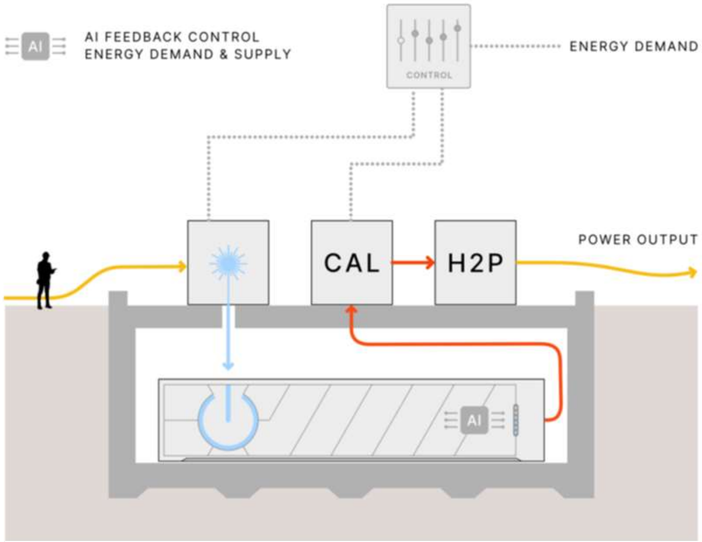
1. ADES units enable scalable expansion (1 ADES = 25MW(th) * 1, 2, 3,...)
2. Converter modules support client-specific configurations based on their individual general profiles (left picture)
3. AI adapts heat production in real time by learning the client's load profile and adjusting Injector runtime *(right picture)*



The following converter (red) modules are available:

- Heat to Electric Power
- Heat to Hydrogen
- Heat to Heat

Depending on the customer's load profile, more or fewer CAL Store storage modules can be added to ADES.



Integrated Unit

ADES VS. OTHER SMR´S – OUR EDGE IN A COMPETITIVE FIELD

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Criteria	ADES (Emerald Horizon)	Typical SMRs (e.g., NuScale, Rolls-Royce, GE Hitachi)
Reactor Type	Thorium-based, accelerator-driven subcritical system	Critical (uranium-fueled, partially molten salt or pressurized water)
Safety	Extremely safe (no operation without accelerator)	High safety but still with chain reaction
Waste Problem	Low (short-lived waste)	High
Proliferation Risk	Very low	Lower than large reactors, but still present
Load-Follow Capability	High; suitable for flexible, demand-driven operation	Generally good, but reactor dynamics and regulation may limit ramping
Technology Readiness	5 – 6 (pre-demonstration phase)	Up to 8 (some projects partially in licensing or construction phase)
Commercialization	Early stage, no pilot reactor in operation	NuScale, Seaborg, GE Hitachi already with contracts
Size / Modularity	Container-sized	Modular but container-sized to house-sized
Coolant	Molten salt & liquid metal	Water, sodium, lead or molten salt

Source: Generated with ChatGPT

EXECUTIVE SUMMARY ADES

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The Scalable and Risk-Optimized Solution for CO_2-Free Energy

ON/OFF switch

- ADES has a **passive-safe ON/OFF control unit.**

AI-powered optimization

- ADES **leverages AI** to **adjust its power output** based on the installation location.
- ADES thereby ensures **optimal performance** in **diverse environments.**

No traditional nuclear waste

- **80%** of thorium is **converted** into energy. Even the remainder contains raw materials that **can be reused.** No final repository for nuclear waste is hence necessary.
- ADES **produces 0% transuranic waste** of Plutonium, Neptunium, Americium and Curium, … known as "nuclear waste".
- It only produces radioactive fission products with short half-lives.

No critical chain reaction

- **ADES runs subcritically.**
- When the injector impulses the thorium, it causes a reaction - **but no critical chain reaction** - making ADES much safer than conventional nuclear power plants.
- Zero explosion risk since there is NO overpressure and NO water / steam.
- No Tl-208 production

Minimum maintenance

- The final ADES module **will not need to be serviced** continuously.
- A **Safety Security Environment Software** will ensure safe control.
- No refueling required for 20 years
- Low operating expenses (OPEX)

1 x ADES module: **25 MW(th) = 10 MW (el) for 20 years**

.. can be combined
to create the largest system in the world!

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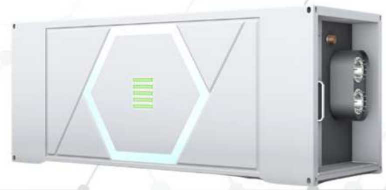
CALstore - A MOLTEN SALT ENERGY STORAGE SYSTEM

CALstore is a 5 MWh Molten Salt Energy Storage System to balance energy oversupply with required demand.

It is non-degrading, affordable, scalable, and free of toxic ingredients.

The system maintains stability in both **low and high temperature** conditions.

- As salt has a high energy density, CALstore **stores large amounts of energy (5 MWh)** which can be released when needed
- The system is **entirely water-free**, eliminating the risk of vapor pressure or detonation gas reactions.
- **Abundant, cheap, and well available salts** like potassium nitrate and sodium nitrate are used. These salts have the capacity to store substantial amounts of energy in a minimal space.
- **The configuration is adaptable** (salt mixture, storage capacity and temperature range) depending on the specific energy input and output requirements. The **scalability of the system** ensures mass-production.
- As the system is not degrading, **the storage capacity remains constant** over the life-cycle and requires only minimal maintenance.



CALSTORE
high temperature liquid-salt energy storage system
FFG
Austrian
Research Promotion Agency
The prototype development:
Modulare high temperature-liquid-salt energy store
is funded by FFG within their base-programme!
2023-2026 FFG-project-number: 903946

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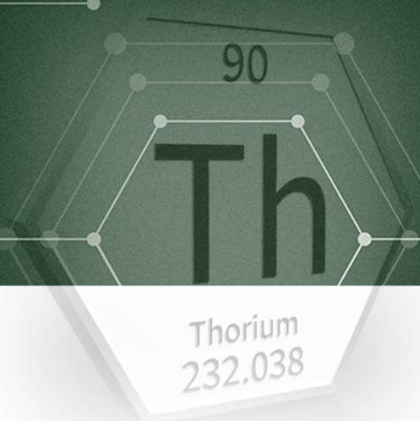
The Neutron Factory based on CERN Technology



FINANCIAL CREDIBILITY

GLOBAL EXPENSION

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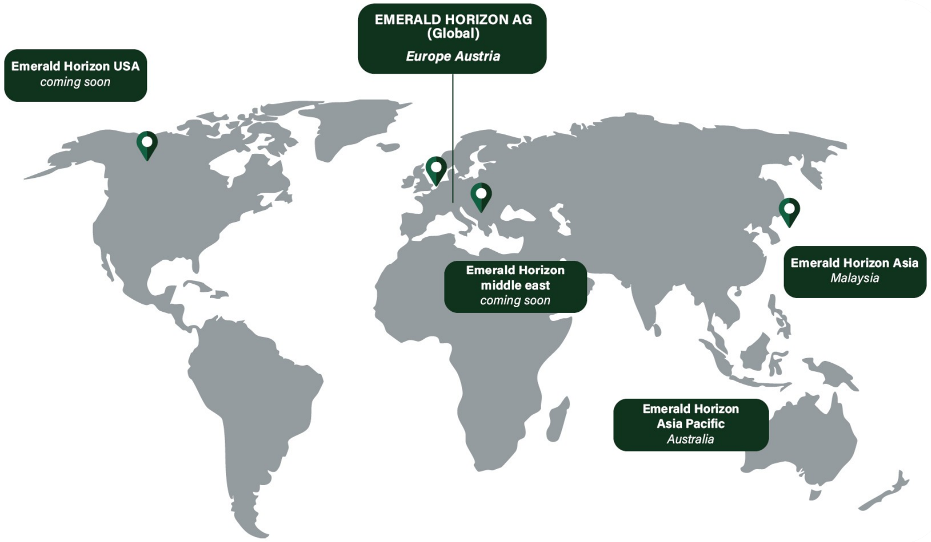
The country organizations are responsible for:

- Handling **regulatory affairs** in their respective regions
- Ensuring stable access to and development of local **sales markets**
- Securing reliable and long-term **capital supply**
- Preparing for future factory setup and operations
- Building demand and market readiness specifically

  for CALStore | ADES | Financial products



PUBLIC CREDIBILITY - NEWSPAPERS | TV | CONGRESS | AWARDS

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KLEINE ZEITUNG

Steirischer Investor will Atommüll zu Strom machen

von Roman Vilgut | 08. November 2019

Business

Green Future | Innovative Wege zur grünen Zukunft

Redaktion | April/Mai 2021

© Klemm/Schandl

Die Presse

Thorium-Reaktoren: Gefährlich oder Zukunftstechnologie?

Redaktion | Mai 2022

DER STANDARD

Suche nach Alternativen - Kann Thorium bei der Energiewende helfen?

Redaktion | August 2022

future zone

Grazer Unternehmen will einen besseren Atomreaktor bauen

Redaktion | September 2022

© Florian Voggeneder

THE RED BULLETIN INNOVATOR

THE REDBULLETIN INNOVATOR

Redaktion | März 2023

St

Grazer Firma bastelt an Atomkleinkraftwerk

Redaktion | November 2022

ORF SOUND

ORF Radio Radio Steiermark, Journal vom 16.11.2022

Redaktion | November 2022

UNDRR
UN Office for Disaster Risk Reduction

UN Climate Initiatives Insights

Emerald Horizon NOMINATED 2025

SPIRIT START-UP AWARD

SFG Steiermärkische SPARKASSE BDO RKP

IMPRINT
Emerald Horizon AG
Emerald LaboraThorium
Karl-Huber-Gasse 15
8041 Graz
Austria
Website: www.emerald-horizon.com
Company register number: FN517877i
Commercial Register Court: Landesgericht für ZRS Graz

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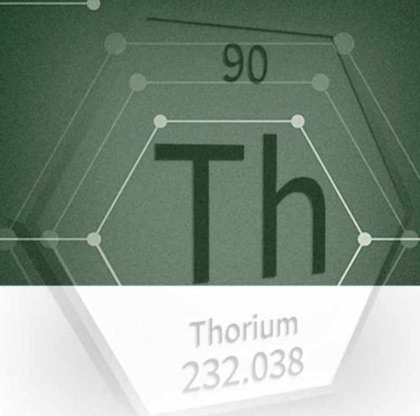
The Neutron Factory based on CERN Technology



TECHNICAL CREDIBILITY

ADES TECHNOLOGY – FOUNDATION

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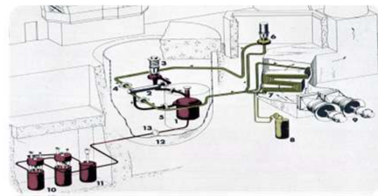
➔ LIQUID CARRIER



MOLTEN SALT REACTOR
OAKRIDGE 60s

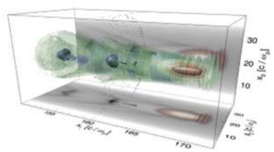
➔ ENERGY/FUEL

THORIUM
USAF 50s

➔ HIGH TEMP

THTR-300
Germany 1983-89

➔ SHRINK ACC



WAKEFIELD
CHIRP 2010+

ADES
accelerator driven energy source

➔ GEOMETRY

FUSION
ITER 50s+

➔ SIZE OF REACTOR

NUCLEAR SUBMARINE
REACTOR CONTAINER-SIZE | 25MW++

➔ ACCELERATOR

ACCELERATOR
CERN 50s+

➔ HEUREKA

AMPLIFIER
Carlo RUBBIA 80+90s

CONCLUSION: All components are based on proven technologies

HQ & TEAM & CO - DEVELOPMENT FOR SERIAL PRODUCTION

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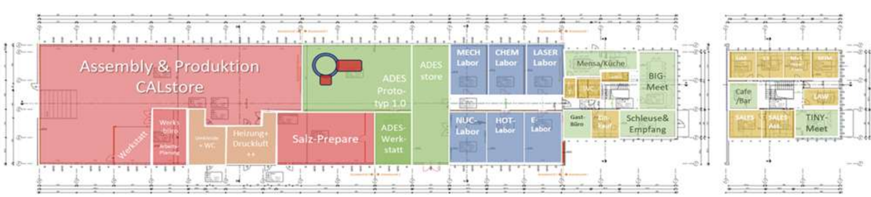
R&D EMERALD HEADQUARTER and CO-development & serial production by European Deep Tech Company



51 people + Partner Multi TEAM & others (internal & external)
Expert-fields are: electrical-, mechanical- & chemical engineering, nuclear physics, LASER & plasma-physics thermodynamics, multi-physics simulations and medical technology.

CONCLUSION: All components are co-developed with established high-tech partners

ADES - KEY MATERIALS: TH-232 & FLUORIDE-SALT

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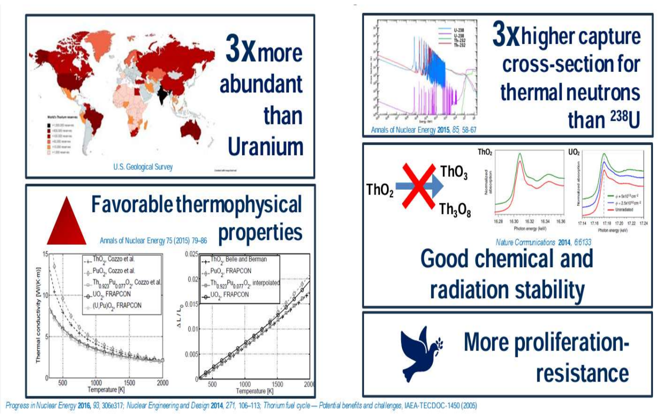
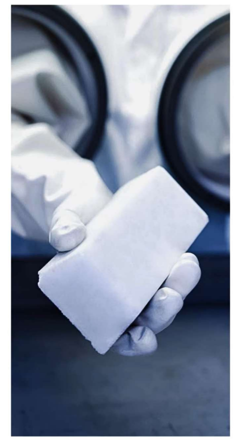


Thorium as chemical element: Th-232, atomic number 90, belongs to the actinide group, is a silvery-white, a weakly radioactive metal. Thorium is 3x more abundant in the Earth's crust than uranium and is often extracted from monazite. It is not directly fissile and does not pose a proliferation risk! For ADES we use Th-232 in fluoride configuration: FLiTh – carrier and energy harvester in one!



- Temperature stability up to > 900 °C
- Efficient heat transfer
- Excellent heat capacity and fluidity
- Chemical inertness and low vapor pressure
- Outstanding neutron transparency with minimal absorption
- Efficient neutron economy in thorium or U-233 systems
- Fluoride chemistry naturally stabilizes actinides as soluble fluorides

ADES ENERGY EQUATION: TRANSMUTING & HARVESTING

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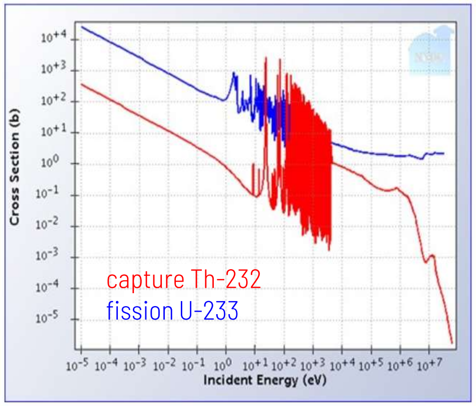


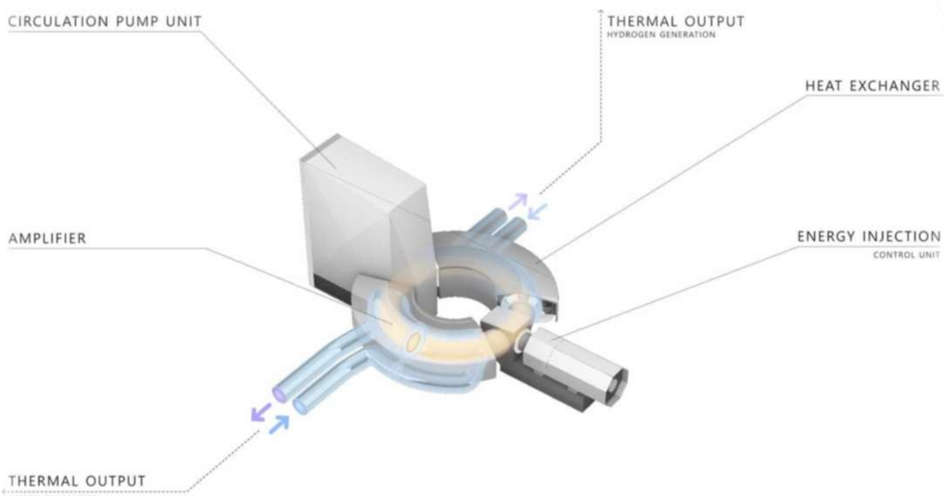
$$E_{\text{fission,total}}(T) = \int_0^T \left(3.204 \times 10^{-11}\right) \sigma_{f,\text{U233}}^{\text{therm}}\, \phi_{\text{therm}}\, N_{\text{U233}}(t)\, dt$$

$$= \left(3.204 \times 10^{-11}\right) \sigma_{f,\text{U233}}^{\text{therm}}\, \phi_{\text{therm}} \frac{\lambda_{\text{Pa233}}\, \lambda_{\text{Th233}}\, \sigma_{c,\text{Th232}}^{\text{epi}}\, \phi_{\text{epi}}\, N_{\text{Th232}}(0)}{\left(\lambda_{\text{Pa233}} - \lambda_{\text{Th233}}\right)\left(\lambda_{\text{Th233}} - \sigma_{c,\text{Th232}}^{\text{epi}}\phi_{\text{epi}}\right)\left(\sigma_{f,\text{U233}}^{\text{therm}}\phi_{\text{therm}} - \lambda_{\text{Pa233}}\right)}$$

$$\times \left[\frac{1 - e^{-\sigma_{c,\text{Th232}}^{\text{epi}}\phi_{\text{epi}}T}}{\sigma_{c,\text{Th232}}^{\text{epi}}\phi_{\text{epi}}} - \frac{1 - e^{-\lambda_{\text{Th233}}T}}{\lambda_{\text{Th233}}} - \frac{1 - e^{-\lambda_{\text{Pa233}}T}}{\lambda_{\text{Pa233}}} + \frac{1 - e^{-\sigma_{f,\text{U233}}^{\text{therm}}\phi_{\text{therm}}T}}{\sigma_{f,\text{U233}}^{\text{therm}}\phi_{\text{therm}}}\right]$$

The ADES equation

$$\phi_{\text{total}} = \frac{S_{\text{ext}}}{V_{\text{core}}}\,\frac{1}{1 - k_{\text{eff}}}, \qquad \phi_{\text{therm}} = f_{\text{therm}}\,\phi_{\text{total}}, \qquad \phi_{\text{epi}} = f_{\text{epi}}\,\phi_{\text{total}}$$



System Parameters (typical magnitudes)

Symbol	Description
V_{core}	Active reaction volume
S_{ext}	External neutron source strength (e.g. Li(p,n) or D(d,n))
k_{eff}	Effective neutron multiplication factor (subcritical)
T	Operation time horizon
f_{therm}	Fraction of the total neutron flux in the **thermal spectrum**
f_{epi}	Fraction of the total neutron flux in the **epithermal spectrum** ($f_{\text{therm}} + f_{\text{epi}} = 1$)
$\sigma_{c,\text{Th232}}^{\text{epi}}$	Microscopic **capture cross section** of Th-232 for epithermal neutrons (Th-232 → Th-233)
$\sigma_{f,\text{U233}}^{\text{therm}}$	Microscopic **fission cross section** of U-233 for thermal neutrons
$\sigma_{c,\text{U233}}^{\text{therm}}$	Microscopic **capture (non-fission)** cross section of U-233 for thermal neutrons
λ_{Th233}	**Decay constant** of Th-233 → Pa-233 (half-life ≈ 22.3 min)
λ_{Pa233}	**Decay constant** of Pa-233 → U-233 (half-life ≈ 26.97 days)
$N_{\text{Th232}}(0)$	Initial inventory of Th-232 atoms (≈ 10 kg)
$N_{\text{Th233}}(t)$	Transient intermediate isotope concentration
$N_{\text{Pa233}}(t)$	Protactinium-233 atoms produced and decaying to U-233
$N_{\text{U233}}(t)$	**Fissile inventory** of U-233 atoms available for fission
E_{fission}	Average **energy released per fission**

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Neutron Yield Confirmation

- Au, Mn activation foils used to measure neutron flux
- MCNP model used to generate target yield from measured flux
- Preliminary result:

  Agreement within uncertainty

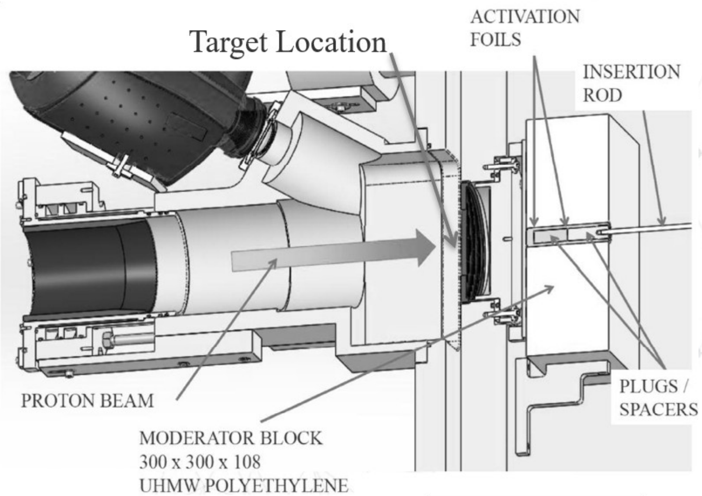
  Measured yield is ~5% lower than prediction

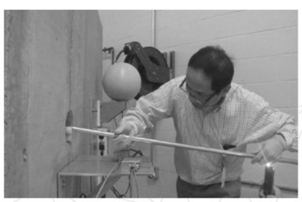
  Estimated uncertainties:

  Measurement: <10%

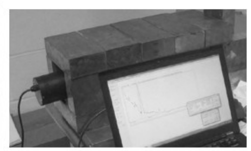
  Simulation: <20%

  - Expected total neutron yield for the case tested @ 2MeV, 25mA and one petal out of 16 coated with Li: **1.64e11 n/s.**
  - Measured initial target yield according to activation measurements & MCNP model (adjusted for target yield degradation over time): **1.57e11 n/s**

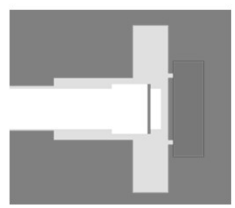




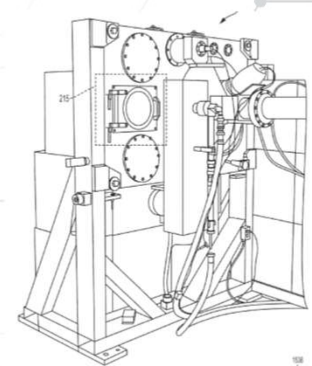
Inserting the Activation Foils

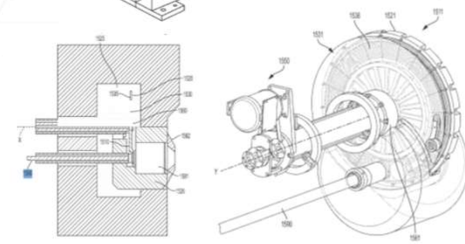


Measuring the Activation



MCNP Model





US-pat.: 2021/0272716 A1

- Diameter of the target wheel: 0.84 m (840 mm)
- Rotational speed: 10 Hz (equivalent to 600 RPM)
- Radial width of the lithium segment: 0.14 m (140 mm)
- Lithium layer thickness: 400 µm

R&D FOR SIZE REDUCTION WITH CANS, LWFA & TNSA

A **particle accelerator** for controlled nuclear reactions enables the **subcritical utilization of nuclear energy**, operating without the risk of an uncontrolled chain reaction.

By accelerating protons or deuterons, neutrons are produced, which can induce **transmutation and/or fission** in heavy nuclei such as thorium or uranium.

Conventional particle accelerators are of **immense size** (SLAC/USA 3 km linear, LHC/CERN – 27 km circular). Therefore, Emerald Horizon is investigating **CANS** (Compact Accelerator-Driven Neutron Sources) and developing **LWFA/TNSA**-based injector technologies as the core driver for the ADES system.

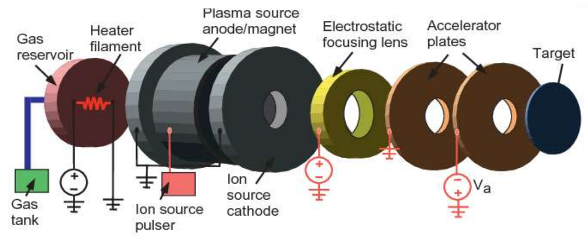
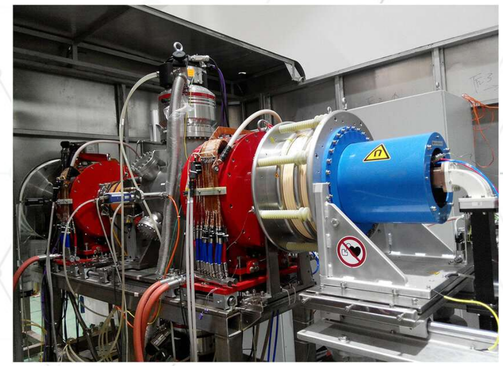
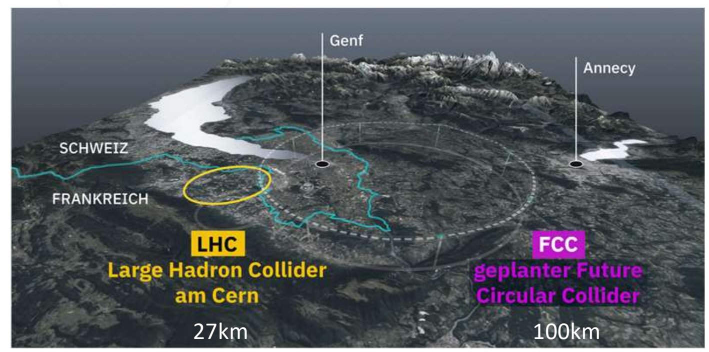


Fig. 1: Conventional accelerator based neutron generators





SMR COMPETITOR COMPARISON

Technologies with a development horizon of 10+ years that have been made visible (press releases, databases, platforms) and are serious competitors to Emerald must show affinity in the following categories:

1. High energy density
2. Molden salt and liquid metal technology
3. High temperature technology (> 500°C)
4. Scalability for energy source and storage
5. Modular mechanical engineering solution with potential for industrial series production
6. Energy source and/or storage for nuclear energy without chain reaction
7. Primary energy source thorium (no uranium or plutonium)

There are technological competitors, in the segment of SMRs (Small Modular Reactors) to which Emerald's ADES can be partially assigned, in individual areas, but none that cover all 7 areas described above.

Name	Design organisation	Headquarter (city/region)	Country	Thermal power (MWth)	Outlet temperature (°C)	Spectrum (thermal/fast)	Fuel type
ARC-100	ARC Clean Technology	Saint John, New Brunswick	Canada	286	510	Fast	Metallic U-Zr alloy
CAREM	CNEA[1]	Buenos Aires	Argentina	100	326	Thermal	UO_2 pellets
ACPR50S	CGN[2]	Shenzhen	China	200	321.8	Thermal	UO_2 pellets
ACP100	CNNC[3] and NPIC[4]	Hainan Province	China	385	319.5	Thermal	UO_2 pellets
Nuward	EDF[5]	Paris	France	540	307	Thermal	UO_2 pellets
BWRX-300	GE-Hitachi/ Hitachi-GE	Wilmington, North Carolina	United States	870	287	Thermal	UO_2 pellets
Hermes	Kairos Power	Alameda, California	United States	35	585	Thermal	TRISO pebble
SEALER-55	Leadcold Reactors	Stockholm	Sweden	140	432	Fast	Uranium nitride
Stable Salt Reactor - Wasteburner	Moltex Energy	Saint John, New Brunswick	Canada	750	590	Fast	Molten salt fuel
VOYGR	NuScale Power	Portland, Oregon	United States	250	321	Thermal	UO_2 pellets
Aurora	OKLO	Sunnyvale, California	United States	4	500	Fast	Metallic U-Zr alloy
Rolls-Royce SMR	Rolls-Royce SMR Ltd	Manchester	United Kingdom	1 358	325	Thermal	UO_2 pellets
KLT-40S	Rosatom	Moscow	Russia	150	316	Thermal	UO_2 pellets
RITM-200N	Rosatom	Moscow	Russia	190	321	Thermal	UO_2 pellets
RITM-200S	Rosatom	Moscow	Russia	198	318	Thermal	UO_2 pellets
Natrium	TerraPower	Bellevue, Washington	United States	840	500	Fast	Metallic U-Zr alloy
HTR-PM	INET[6]	Beijing	China	500	750	Thermal	TRISO pebble
MMR	Ultra Safe Nuclear	Seattle, Washington	United States	15	630	Thermal	TRISO prismatic
U-Battery	Urenco	Stoke Poges	United Kingdom	10	710	Thermal	TRISO prismatic
eVinci	Westinghouse Electric Company	Cranberry Township, Pennsylvania	United States	13	750	Thermal	TRISO
XE-100	X-energy	Rockville, Maryland	United States	200	750	Thermal	TRISO-X pebble

Source: NEA Small Modular Reactor Dashboard (2023)

SCIENCE LINKS

emerald horizon

[Microsoft Word - MSadventure.doc]

[Molten-salt reactor information system (Technical Report) | OSTI.GOV]

[Molten salt reactors: A new beginning for an old idea]

[Thorium Resources as Co- and By-products of Rare Earth Deposits | IAEA]

oecd-nea.org/trw/docs/rubbia/concept.pdf

oecd-nea.org/trw/docs/rubbia/concept.pdf

nucleus.iaea.org/sites/fusionportal/Shared Documents/PC_8663_Fusion_Competition.pdf

Key World Energy Statistics 2021

Nuclear Power in the World Today - World Nuclear Association

Advances in Boron Neutron Capture Therapy