NUCLEARE: PROSPETTIVE E TEMPISTICHE

Transizione Energetica: esiste un ruolo per il Nucleare?

prof. Marco Ricotti
Politecnico di Milano, Dept. of Energy
CeSNEF-Nuclear Engineering division

FONDAZIONE CARLOPERINI

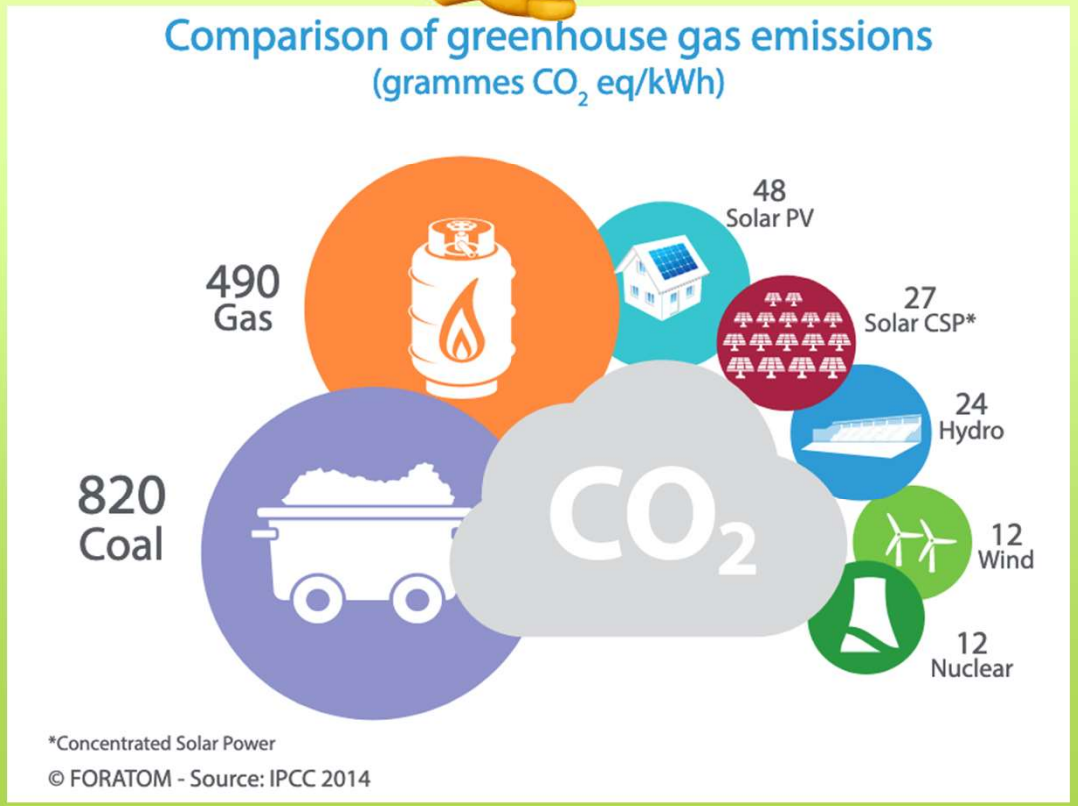
ORDINE DEI DOTTORI AGRONOMI E DEI DOTTORI FORESTALI

OCF ORDINE INTERPROVINCIALE DEI CHIMICI E DEI FISICI DELLA LOMBARDIA

TRANSIZIONE: CON QUALI ENERGIE
Milano
2022 Giugno 18

SI e NO

Perché SI



Perché NO

«Not a Sound Business in Western World»

(ma una differente esperienza nel Mondo non-Occidentale)

EPR - Olkiluoto Unit 3

Start 2004 | Planned COD 2009 | COD Dec. 2022

10+ Years Delay

Original Budget 3.2B€ | Expected 12 B€

8.8 B€ overrun, +270%

AP1000 - Vogtle Units 3 & 4

VC Summer: stopped

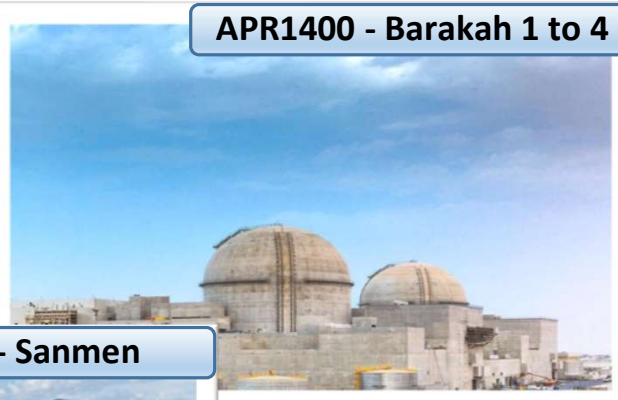
Start 2012 | Planned COD 2016 | Expected COD 2023

7+ Years Delay

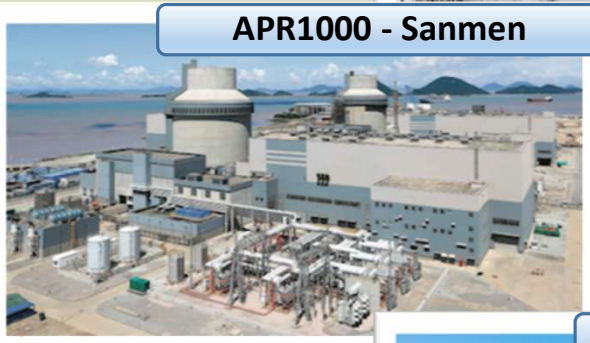
Original Budget 14B$ | Expected 26 B€

12+ B$ overrun, +85%

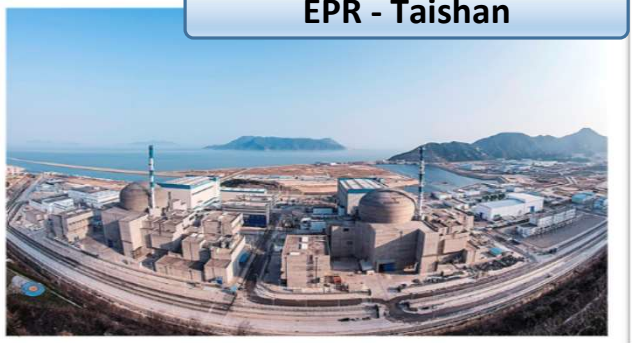
APR1400 - Barakah 1 to 4



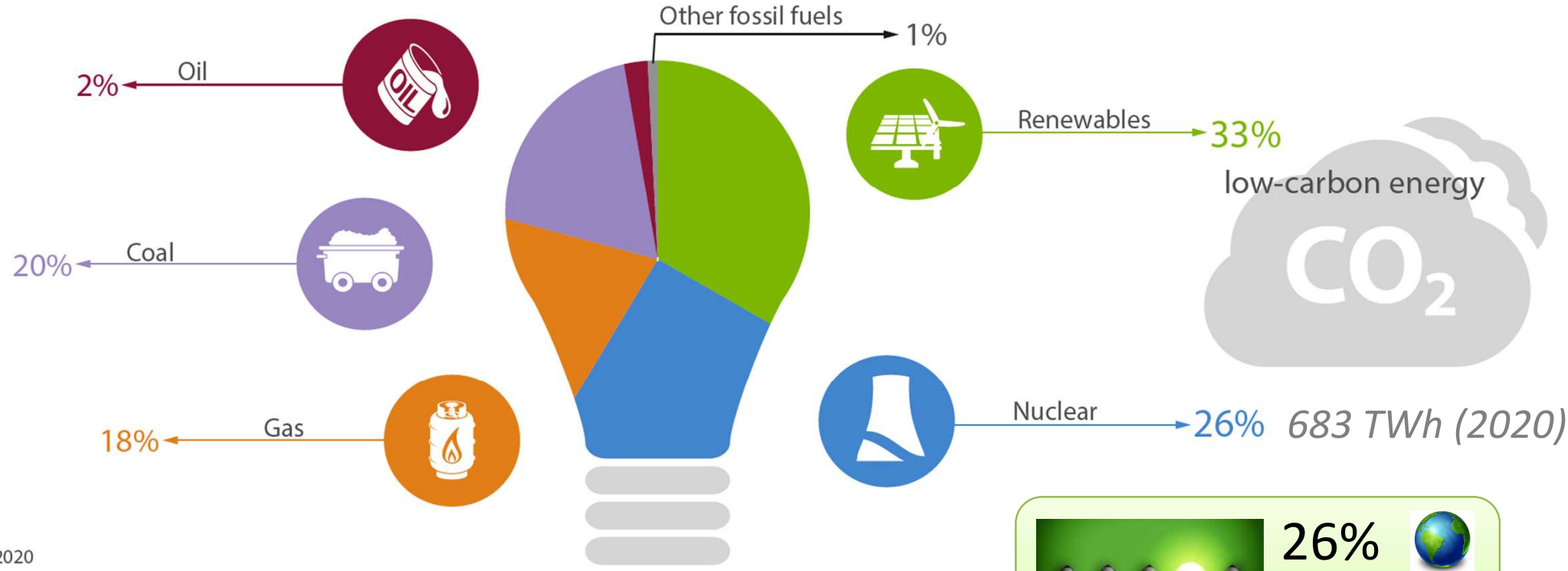
APR1000 - Sanmen



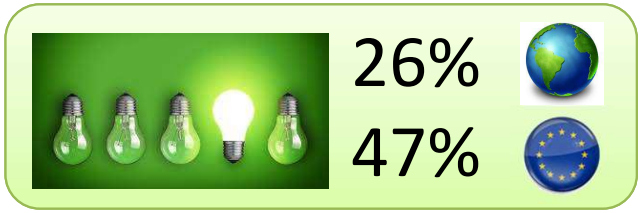
EPR - Taishan



Ruolo del nucleare OGGI (EU)
Produzione di elettricità per fonte

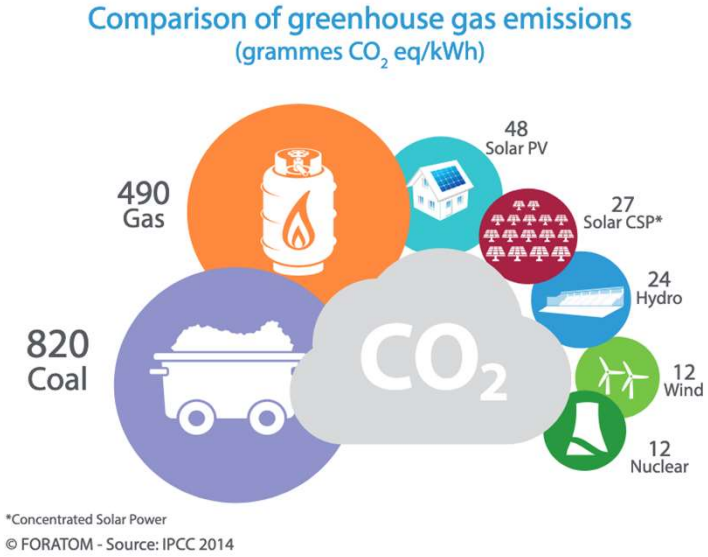


Source: Eurostat 2020



Il nuovo Trilemma
(non solo Global Warming…)

(I) Global warming



(II) Dipendenza energetica

Quasi intero ciclo produttivo nucleare in EU (inclusi brevetti-IP):

- materia prima Uranio da paesi «non-critici» (Canada e Australia)
- arricchimento e fabbricazione: EU; progettazione e costruzione reattori: EU

(III) Ricadute economiche

- Filiera industriale ampia
- Industria manifatturiera «pesante» e «leggera», di qualità
- Numero di lavoratori coinvolti, formazione
- **>80% investimento in EU**

Lo scenario tecnologico

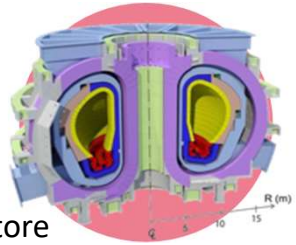
Gen II

Quasi tutti i reattori oggi in funzione. Estensione della vita operativa (da 40 a 60-80 anni)

Small Modular Reactors

Piccola taglia (< 300 MWe), progettazione e costruzione modulari.

Fusione DEMO

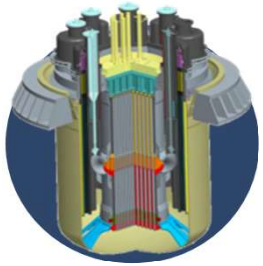


Primo reattore (commerciale) a fusione

Gen III (Gen III+)

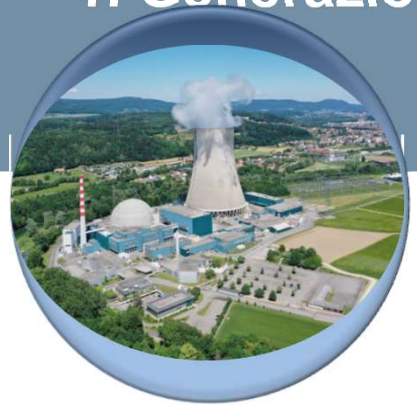
Alcuni già operativi (Cina, UAE, Corea Sud, Russia, India).
La maggioranza dei 51 reattori in costruzione nel Mondo

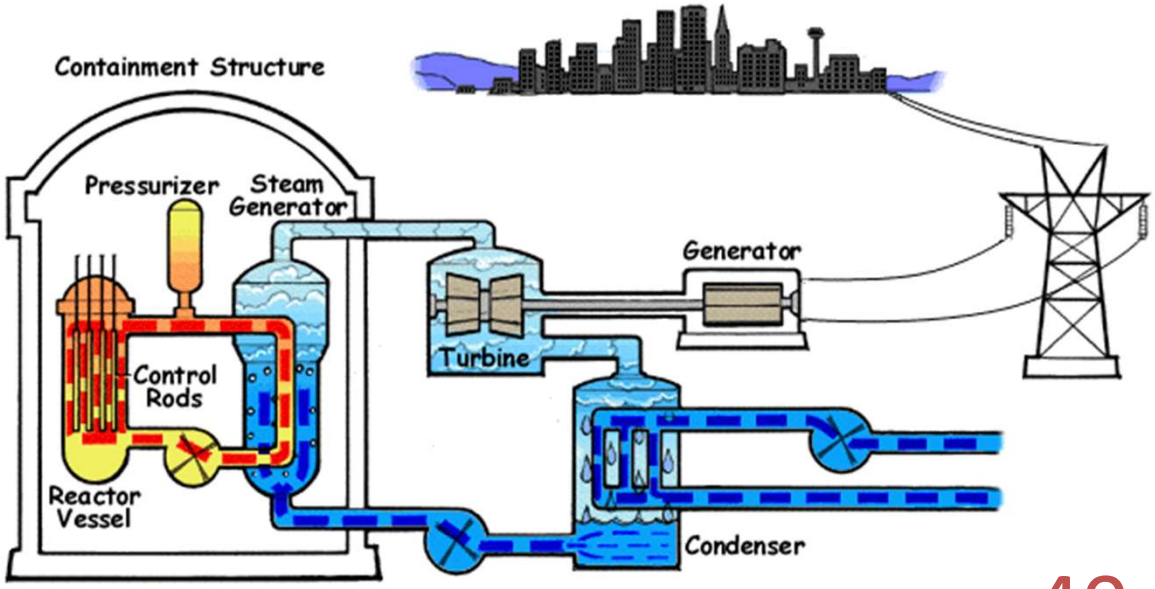
Gen IV



Raffreddamento a metallo liquido o a Sali fusi. Possibilità di riciclare i rifiuti a vita lunga e ad alta radioattività.

1. Generazione II: Estensione di Vita





Reattori:

441

106

Anni di esperienza:

19 200

Funzionamento:

40 anni

EXTRA TIME

60 anni

2. Generazione III: In costruzione & Operativi

Reattori:

51

(se Generazione III: No Fukushima)

2. Generazione III: In costruzione & Operativi

Sicurezza Attiva

EPR Strategy:

- Economia di scala
- Sicurezza attiva & ridondanza (4×100%)
- Incidente severo gestito “ex-vessel” (core catcher)

Mix (Attiva+Passiva)

AES Strategy:

- Sistemi di sicurezza attivi & passivi
- Incidente severo gestito “ex-vessel” (core catcher)

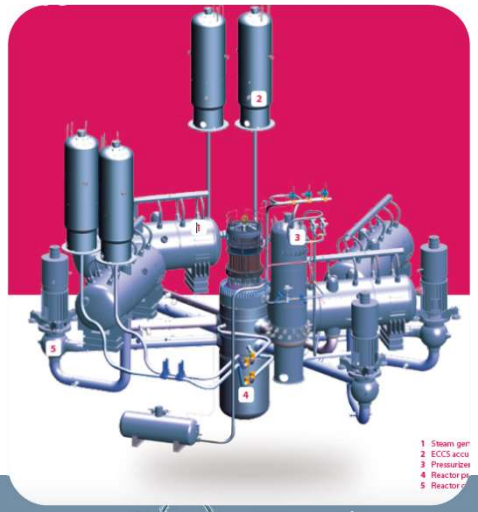
Sicurezza Passiva

AP1000 Strategy:

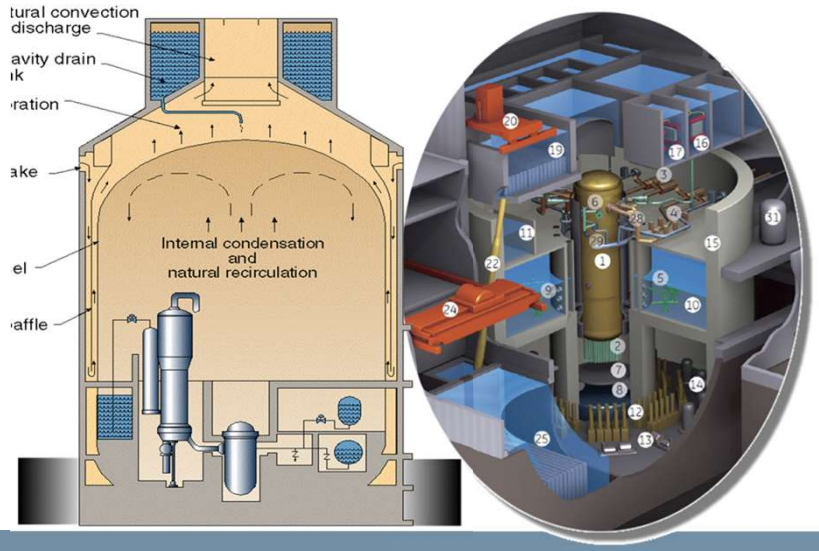
- semplificazione, modularizzazione
- Sistemi di sicurezza passivi
- Incidente severo gestito “in-vessel” (in-core retention)

EPR (FRA)**, ABWR** (USA)

AES-2006 (VVER 1200) (Russia)

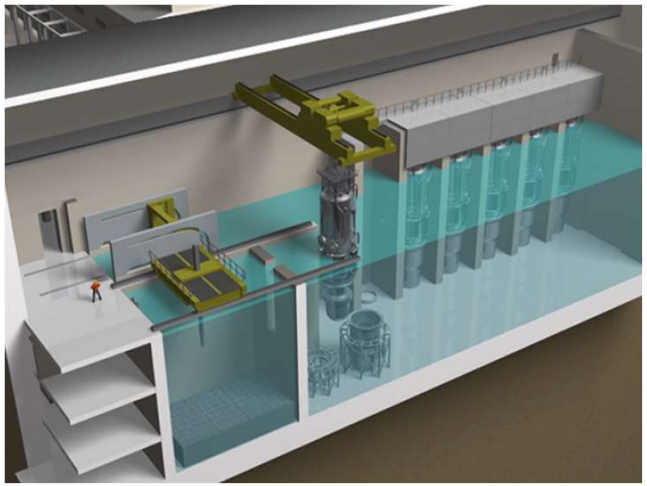


AP1000, ESBWR (USA)



3. Small Modular Reactors: In Piccolo

Reattori nucleari di taglia limitata (< 300 MWe)

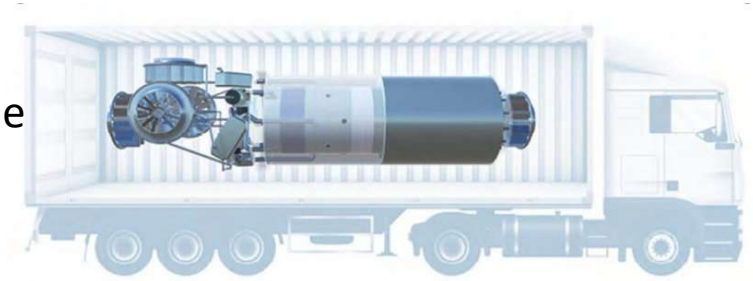


Vantaggi:

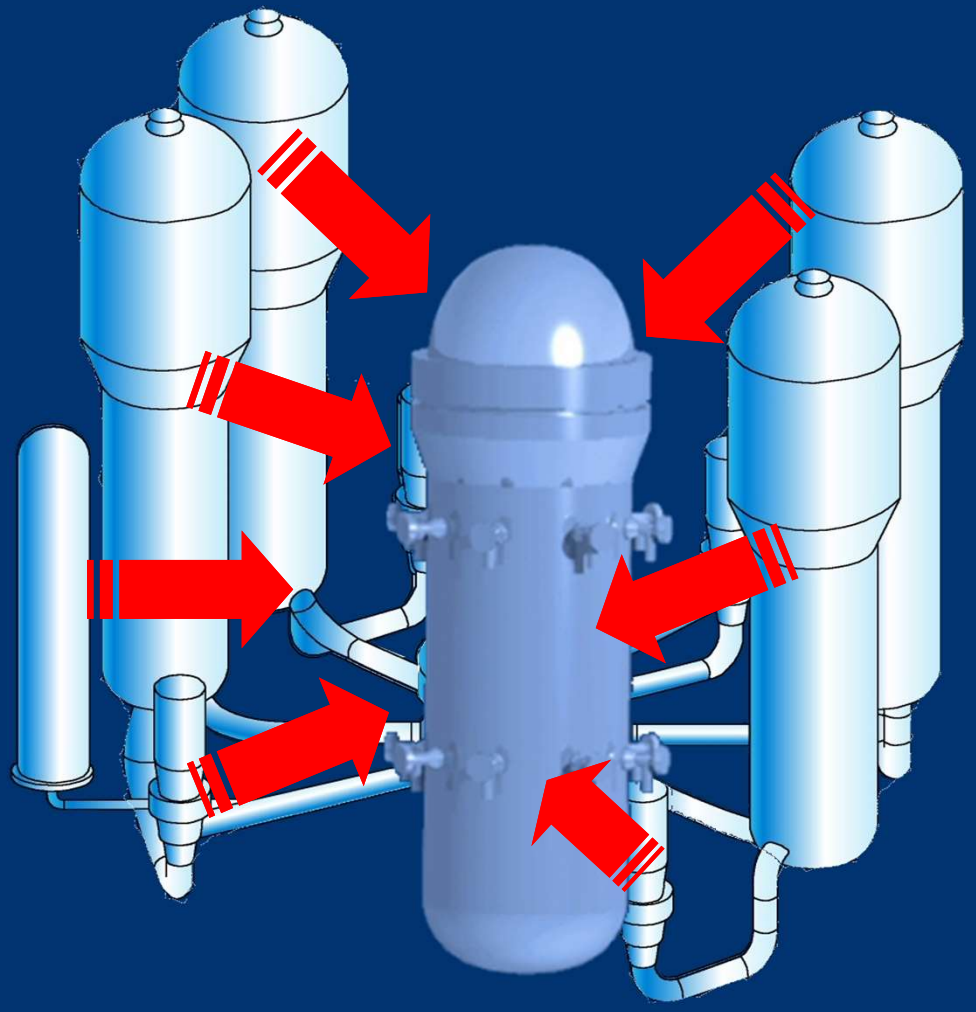
- Design **semplificato**
- Strategia di sicurezza a «**sistemi passivi**» (circolazione naturale: no Fukushima)
- Progettazione e costruzione **modulare**, in officina
- **Cogenerazione** (idrogeno, accumulo termico, teleriscaldamento, desalazione, biofuel)

Sfide:

- Mercato internazionale, costruzione in serie
- Dimostratori: tempi e costi



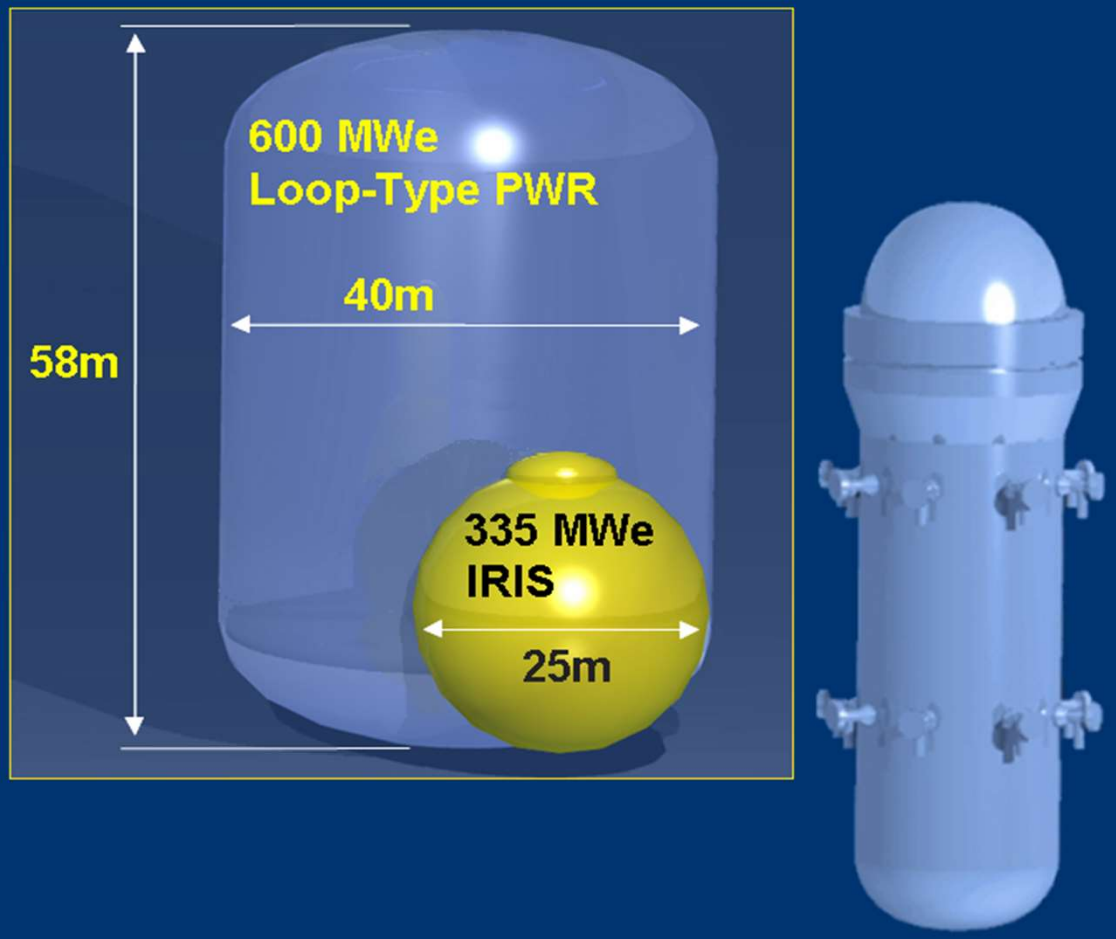
3. Small Modular Reactors: In Piccolo



The Integral solution allows to:

- **eliminate** piping and external components,

3. Small Modular Reactors: In Piccolo



The Integral solution allows to:

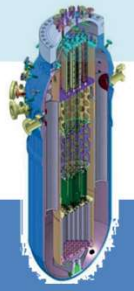
- **eliminate** piping and external components,
- adopt a **compact containment**
- **reduce** plant footprint

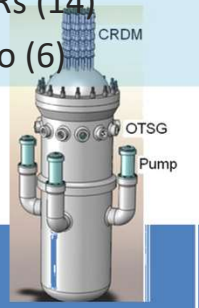
3. Small Modular Reactors: In Piccolo

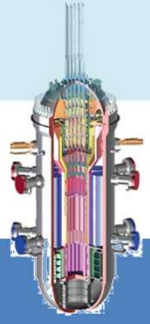
>70 SMR/AMR progetti in fase di sviluppo nel Mondo, taglia: da 1-5 MWe (micro) a 300 MWe

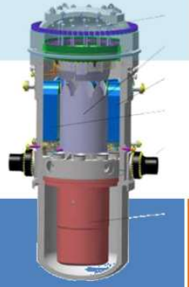
Land Based WCRs (25) Marine Based WCRs (6) HTGRs (14)

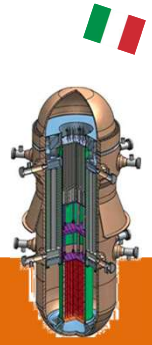
Fast Reactors (11) MSRs (10) Micro (6)





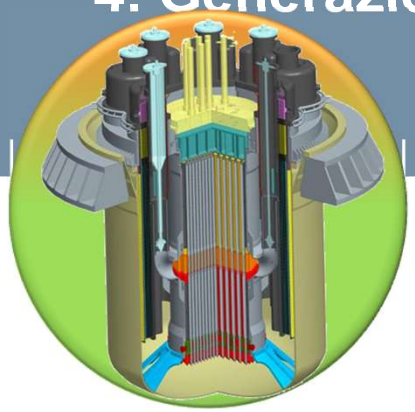






INTEGRATION OF COMPONENTS	CAREM	NuScale	RITM-200	ACP100	SMART	NUWARD	IRIS
Pressurizer	X	X	X	X	X	X	X
Steam Generators	X	X	X	X	X	X	X
Pumps	NatCirc	NatCirc					X
CRDMs	X					X	X
SIZE MWth **MWe**	100 **27**	160 (?) **50 (77)**	165 **52**	310 **100**	330 **100**	540 **170**	1000 **335**

4. Generazione IV: Rifiuti addio



Reattori raffreddati a:
piombo liquido, sodio liquido, sali fusi

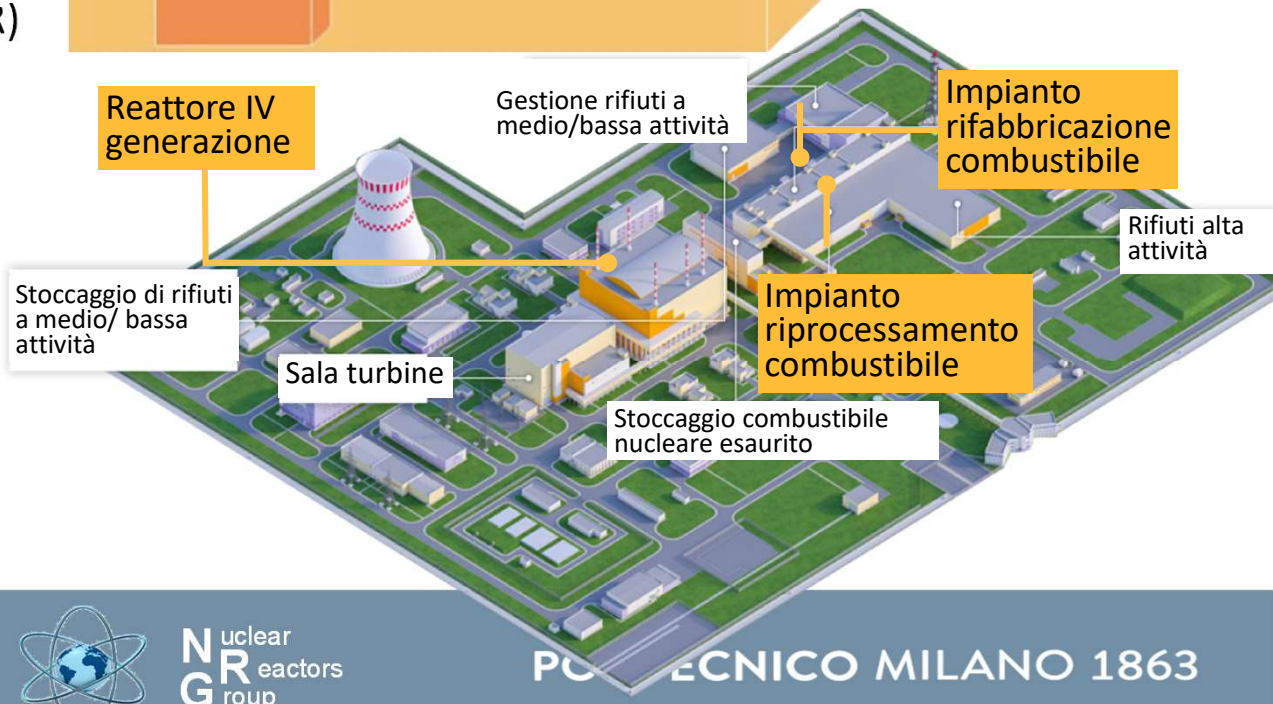
«fisica differente»: eccesso di neutroni

Vantaggi:

- Gli stessi degli SMR (molti GenIV sono SMR)
- Miglior **rendimento**
- Possibilità di **separare e «bruciare» i rifiuti** ad alta radiotossicità

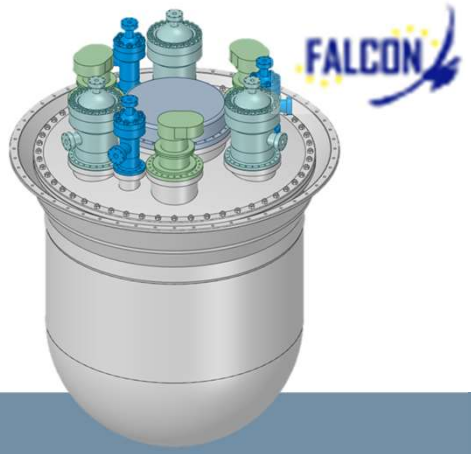
Sfide:

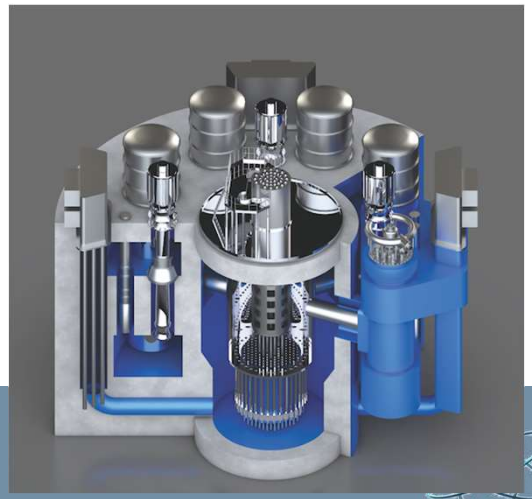
- Economicità
- Integrazione con impianti del ciclo del combustibile (proliferazione)

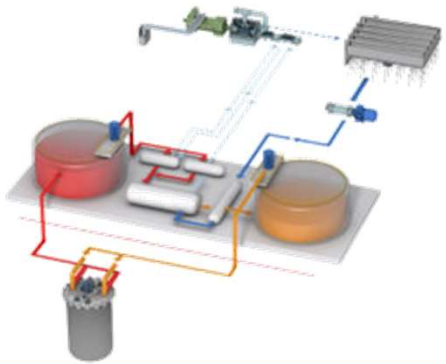


4. Generazione IV: Rifiuti addio

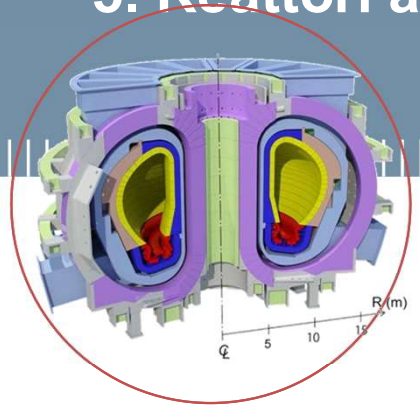
ALFRED (Falcon Consortium, ITA-ROM)	**PRORYV** (ROSATOM, Russia)	**MMR** (USNC – Francesco Venneri) Start-up	**NATRIUM** (TerraPower – Bill Gates) Start-up
• Lead-cooled Fast Reactor (125 MWe) • Exp. facilities in Italia (ENEA Brasimone) • Nuove grandi exp. facilities in Romania • Romania: fondi strutturali EU per ALFRED	• Lead-cooled Fast Reactor (300 MWe) • Accoppiato con impianto riprocessamento + impianto rifabbricazione combustibile • Riciclo di rifiuti ad alta radioattività (burner)	• High Temperature Gas Reactor (5-10 MWe) • Combustibile ceramic Micro-incapsulato (TRISO) • No acqua per raffreddamento, no rete elettrica (strategia “batteria”)	• Sodium Fast Reactor (345 MWe) • Energia termica reattore completamente stoccata in serbatoi Sali Fusi • Cogenerazione disaccoppiata dall’impianto nucleare • Picco 500 MWe >5h

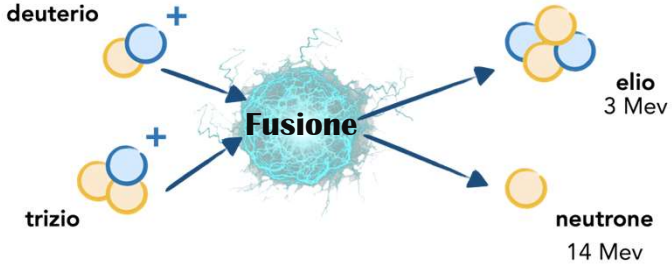


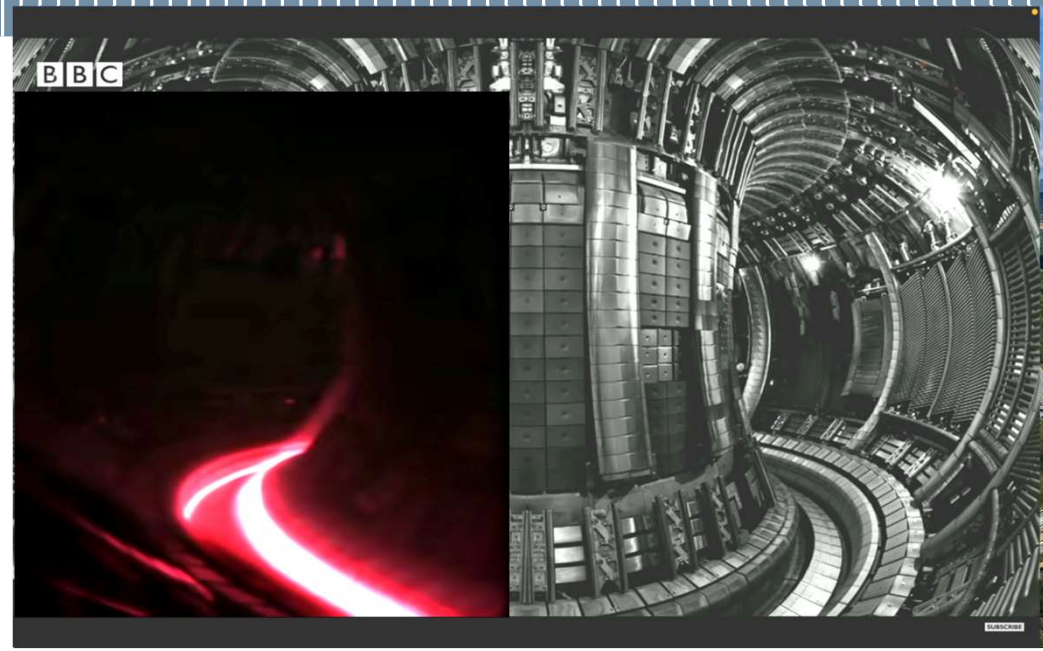




5. Reattori a Fusione: il Sole sulla Terra





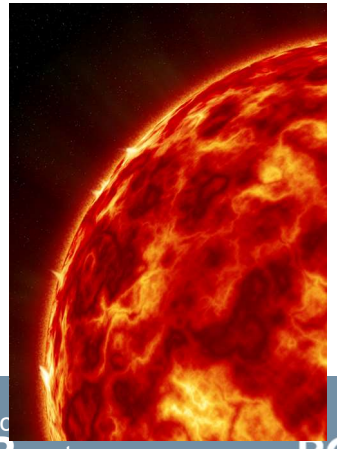


Vantaggi:

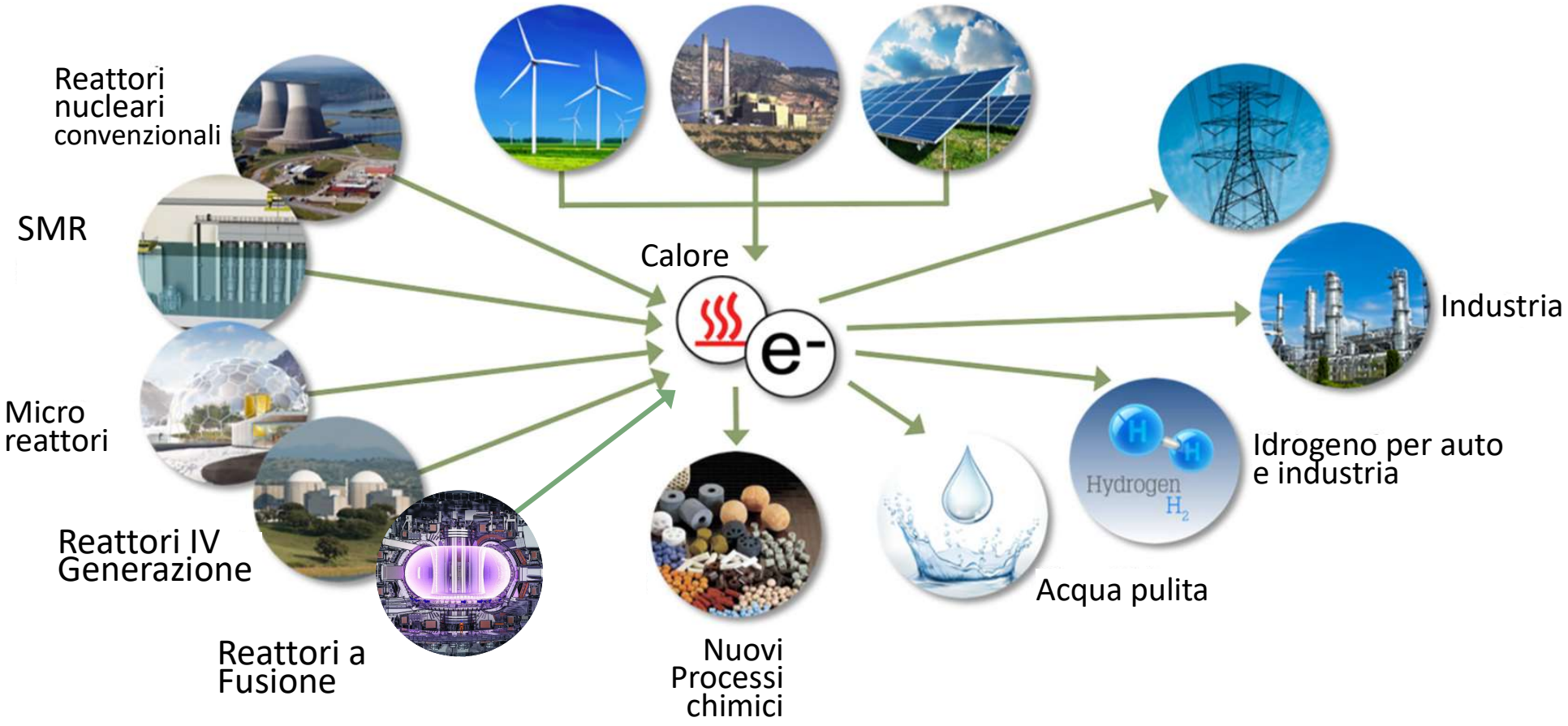
- Abbondanza del combustibile (acqua… + litio)
- Basso impatto ambientale (no emissioni di CO_2)
- Sicurezza
- Rifiuti: pochi e non ad alta radioattività

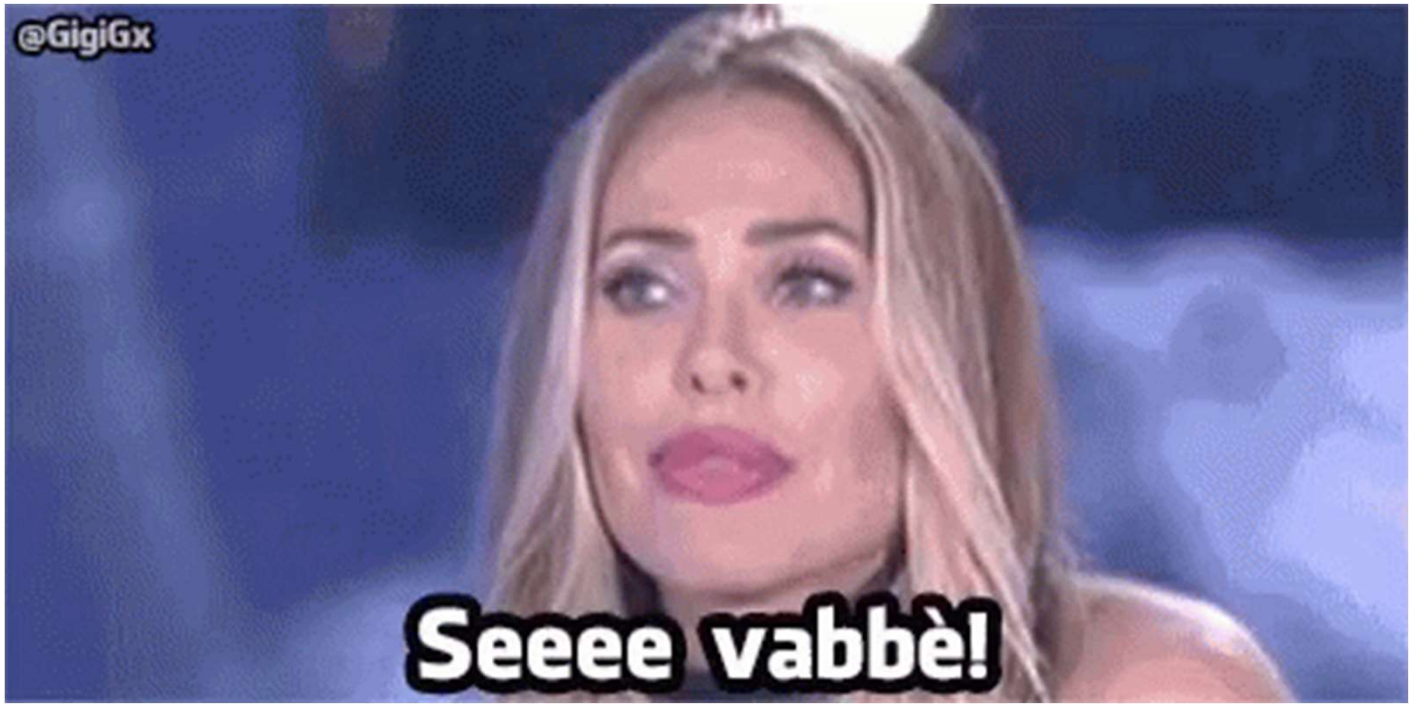
Sfide:

- Complessità del problema fisico
- ..e ancora di più del problema ingegneristico!
- Costi delle strutture di ricerca
- Economia



«*No more CO_2*»: Rinnovabili & Nucleare





«Ma…»

«…ma gli SMR non arriveranno in tempo»

Già operativi

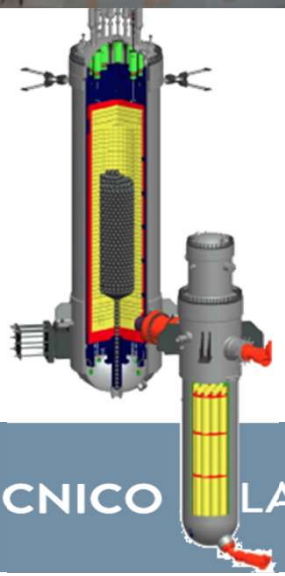
RUSSIA

Barge mounted PWR reactor

KLT40s

CHINA

High Temperature Gas Reactor



HTR-PM

«…i reattori di IV Generazione sono ancora più lontani»

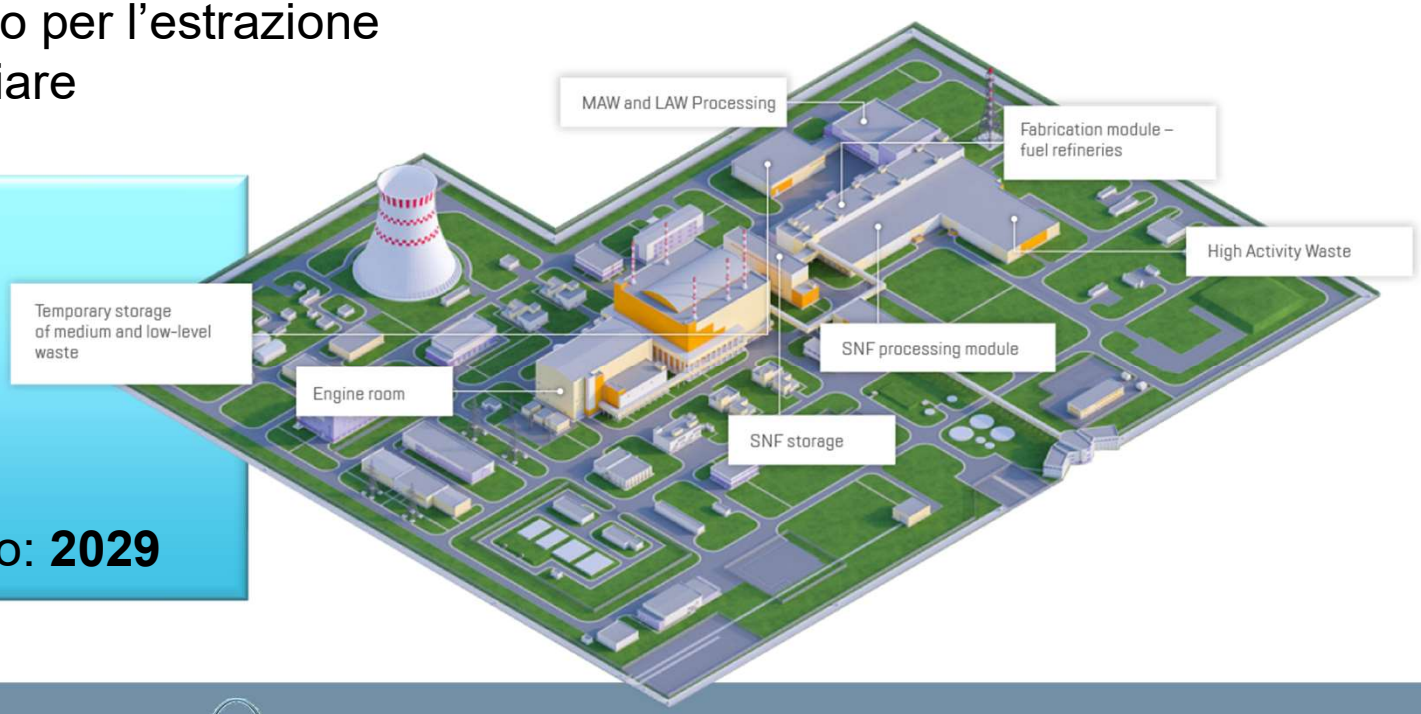
ROSATOM (Russia): progetto PRORYV («*Breakthrough*»)

1. Reattore di IV Gen raffreddato a piombo liquido BREST-OD-300 (300 MWe)
2. Impianto di fabbricazione e ri-fabbricazione del combustibile
3. Impianto di riprocessamento per l'estrazione dei rifiuti radioattivi da bruciare

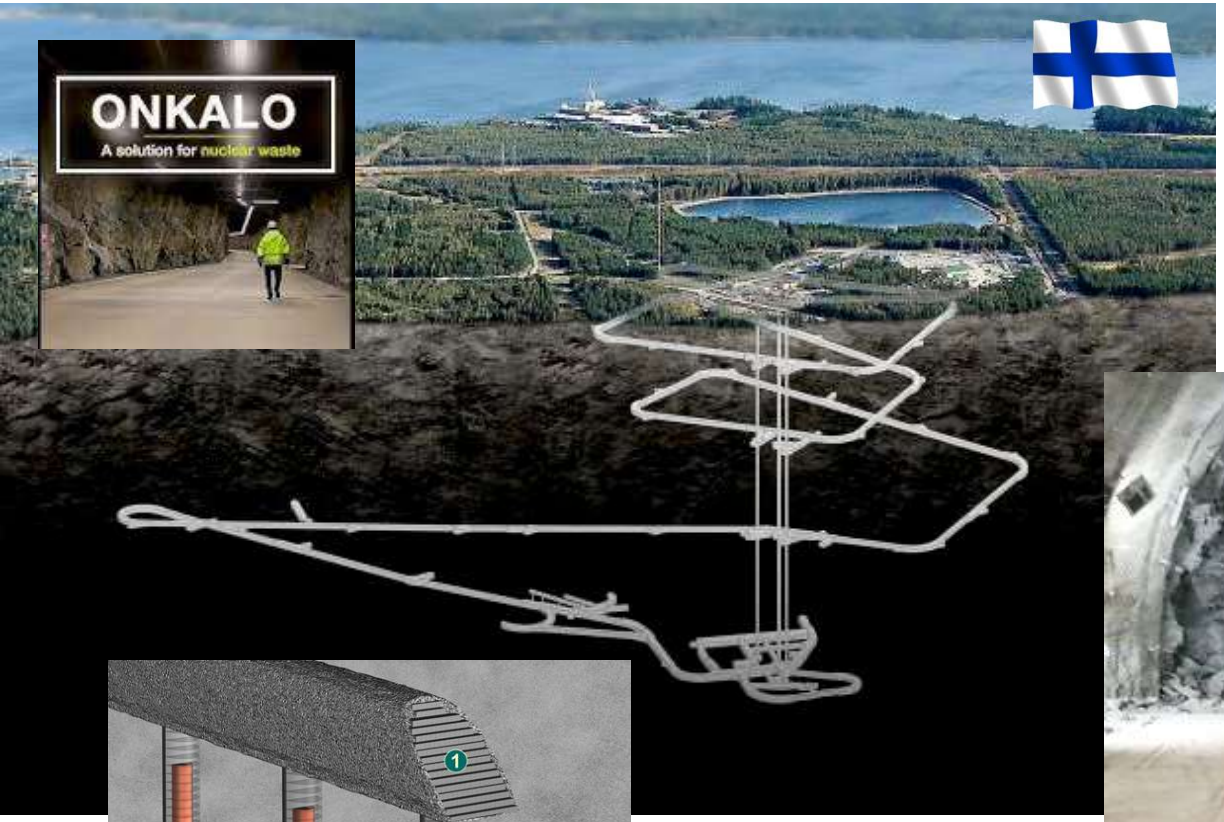
Costruzione reattore iniziata **08/06/2021**, completamento previsto **2026**

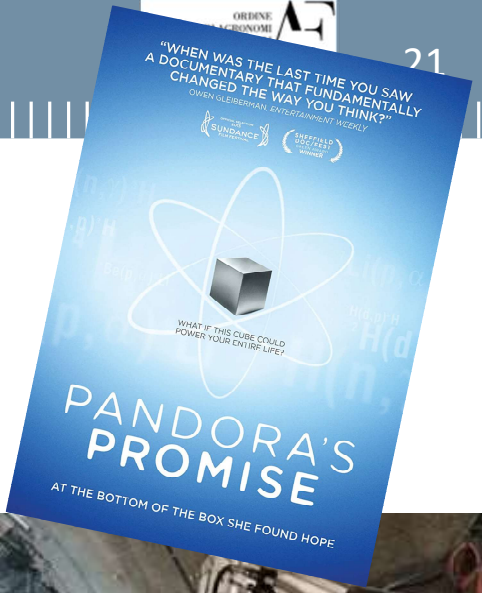
Avvio impianto fabbricazione combustibile: **2024**

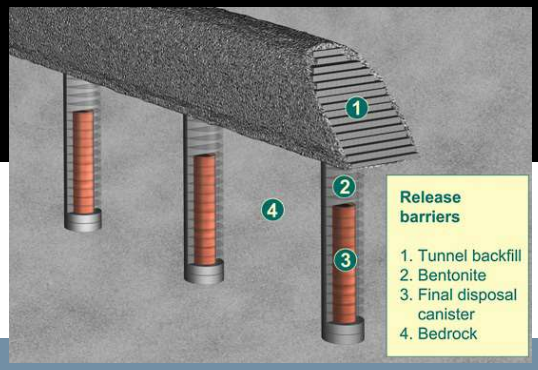
Avvio impianto riprocessamento: **2029**



«…non esiste ancora una soluzione per i rifiuti radioattivi!»







Le capacità italiane: Ricerca & Sviluppo

ANSALDO NUCLEARE Ansaldo Energia Group

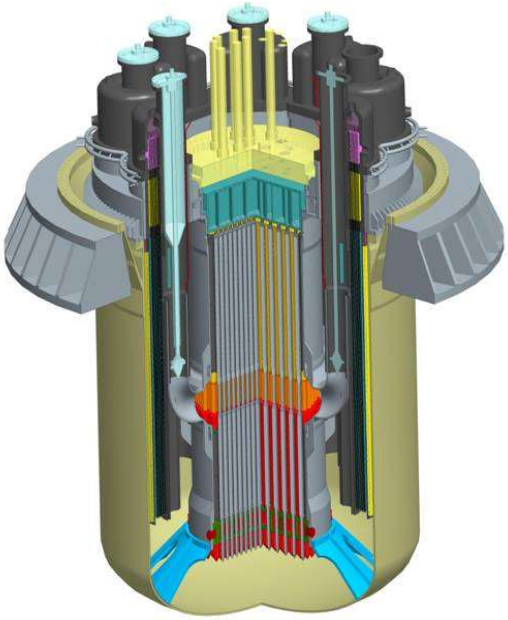
ENEA

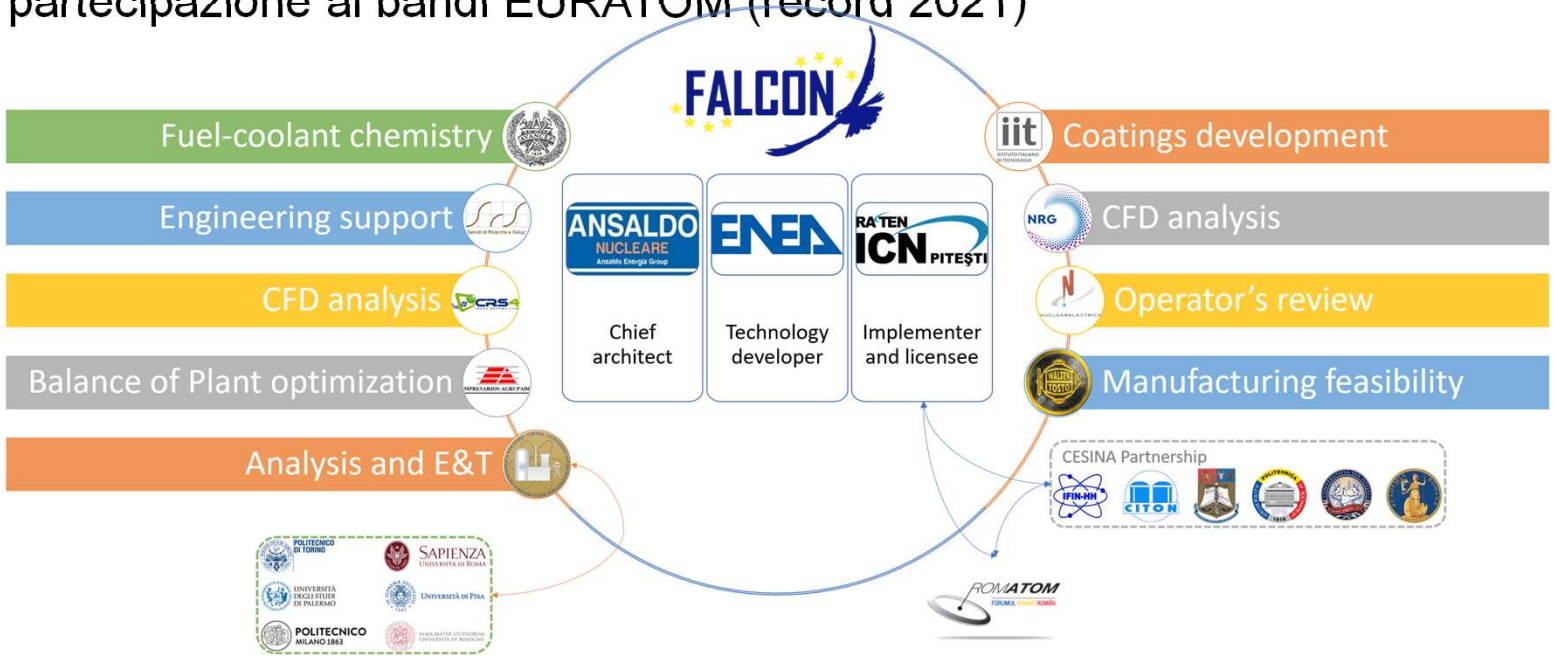
CIRTEN
Consorzio Interuniversitario per la Ricerca TEcnologica Nucleare
Inter-University Consortium for Nuclear Technological Research

SIET sperimentiamo le tue idee

Il «paradosso italico»:

- Assenza di opportunità per finanziamento attività R&S su nucleare-fissione (da 2018)
- Successo nella partecipazione ai bandi EURATOM (record 2021)

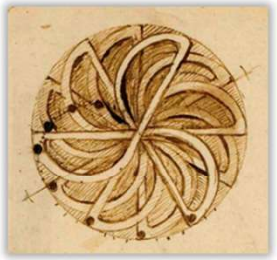




ACCADEMIA NAZIONALE DEI LINCEI

COLLOQUIA ON SCIENCE DIPLOMACY

MMXXII



LEONARDO DA VINCI, CODEX ATLANTICUS (1494)

SPECIAL EVENT
WITH

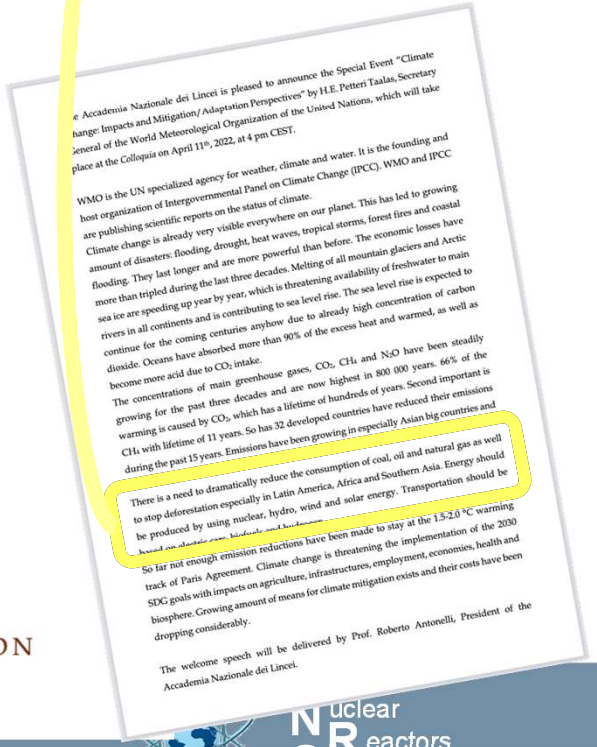
H.E. PETTERI TAALAS

SECRETARY GENERAL
WORLD METEOROLOGICAL ORGANIZATION
OF THE UNITED NATIONS

non-[illegible] countries

There is a need to dramatically reduce the consumption of coal, oil and natural gas as well to stop deforestation especially in Latin America, Africa and Southern Asia. Energy should be produced by using nuclear, hydro, wind and solar energy. Transportation should be based on electric cars, biofuels and hydrogen.

So far not enough emission reductions have been made to stay at the 1.5-2.0 °C warming



e Accademia Nazionale dei Lincei is pleased to announce the Special Event "Climate
hange: Impacts and Mitigation/Adaptation Perspectives" by H.E. Petteri Taalas, Secretary
eneral of the World Meteorological Organization of the United Nations, which will take
place at the *Colloquia* on April 11th, 2022, at 4 pm CEST.

WMO is the UN specialized agency for weather, climate and water. It is the founding and
host organization of Intergovernmental Panel on Climate Change (IPCC). WMO and IPCC
are publishing scientific reports on the status of climate.
Climate change is already very visible everywhere on our planet. This has led to growing
amount of disasters: flooding, drought, heat waves, tropical storms, forest fires and coastal
flooding. They last longer and are more powerful than before. The economic losses have
more than tripled during the last three decades. Melting of all mountain glaciers and Arctic
sea ice are speeding up year by year, which is threatening availability of freshwater to main
rivers in all continents and is contributing to sea level rise. The sea level rise is expected to
continue for the coming centuries anyhow due to already high concentration of carbon
dioxide. Oceans have absorbed more than 90% of the excess heat and warmed, as well as
become more acid due to CO_2 intake.
The concentrations of main greenhouse gases, CO_2, CH_4 and N_2O have been steadily
growing for the past three decades and are now highest in 800 000 years. 66% of the
warming is caused by CO_2, which has a lifetime of hundreds of years. Second important is
CH_4 with lifetime of 11 years. So has 32 developed countries have reduced their emissions
during the past 15 years. Emissions have been growing in especially Asian big countries and

There is a need to dramatically reduce the consumption of coal, oil and natural gas as well
to stop deforestation especially in Latin America, Africa and Southern Asia. Energy should
be produced by using nuclear, hydro, wind and solar energy. Transportation should be
based on electric cars, biofuels and hydrogen.

So far not enough emission reductions have been made to stay at the 1.5-2.0 °C warming
track of Paris Agreement. Climate change is threatening the implementation of the 2030
SDG goals with impacts on agriculture, infrastructures, employment, economies, health and
biosphere. Growing amount of means for climate mitigation exists and their costs have been
dropping considerably.

The welcome speech will be delivered by Prof. Roberto Antonelli, President of the
Accademia Nazionale dei Lincei.

in diretta su RAI Cultura
www.raicultura.it

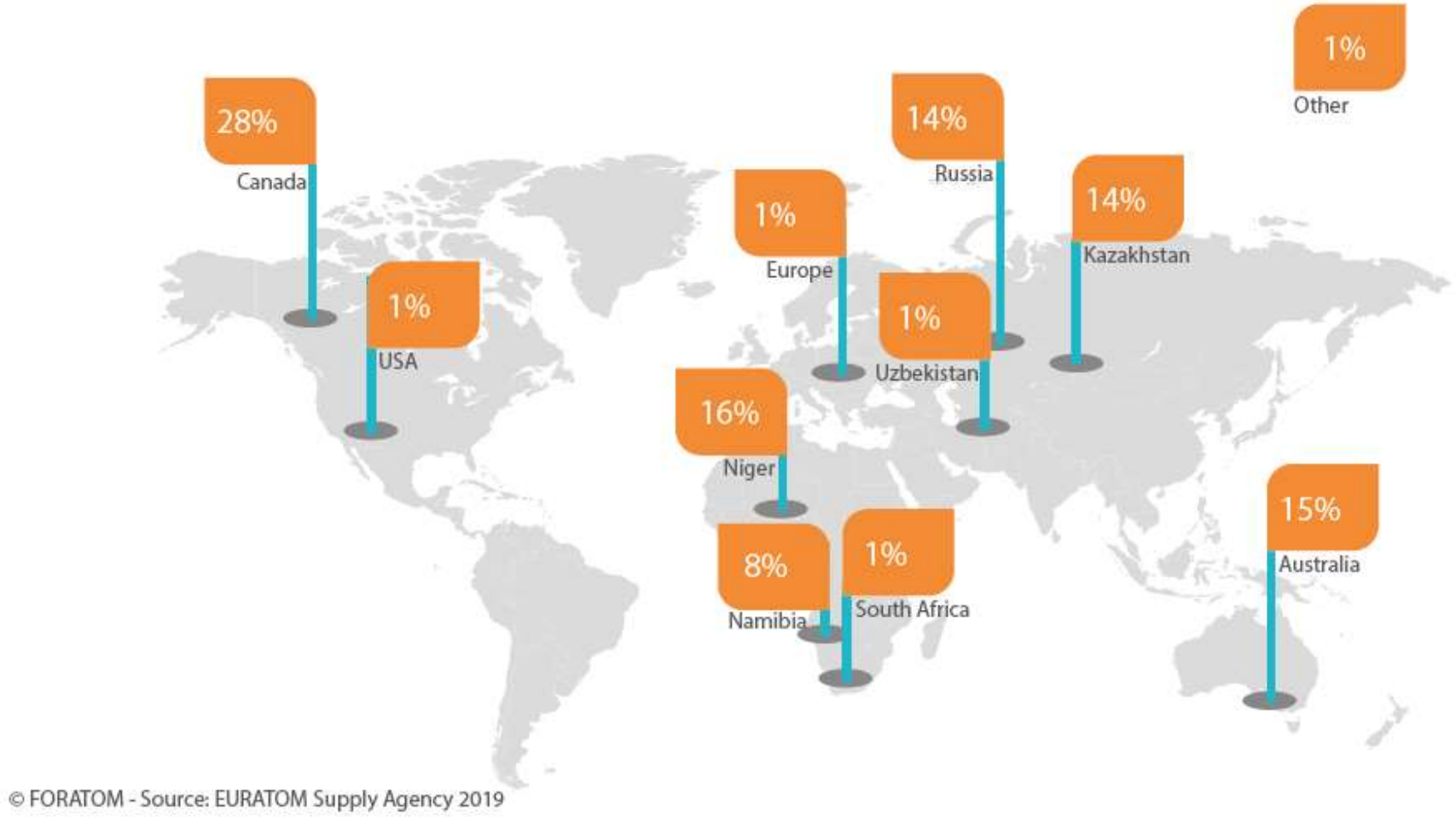
WITH THE COLLABORATION OF

TRECCANI

WITH THE MEDIA PARTNERSHIP OF

Rai Cultura Rai News 24 Rai Radio 1

Chi fornisce Uranio naturale all'EU ?

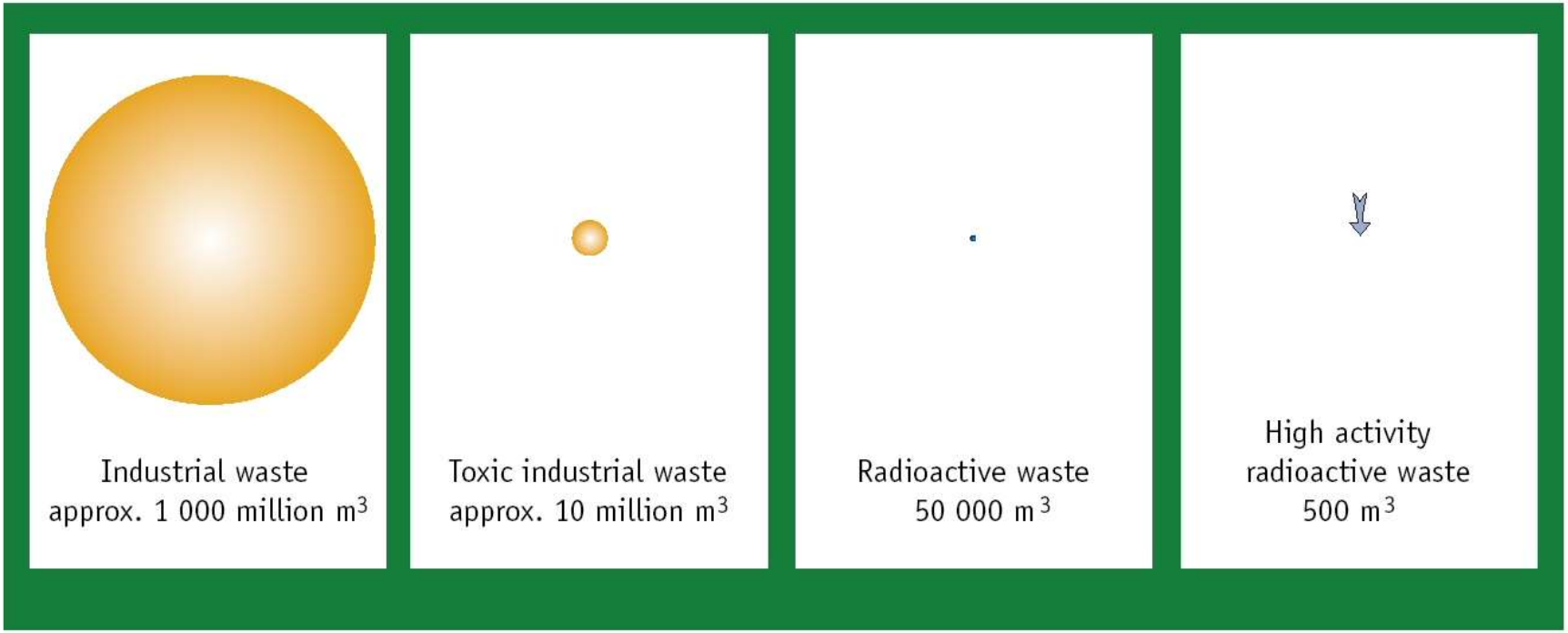


Quanto territorio si usa ?

© FORATOM - Source: Entergy Arkansas, Inc.

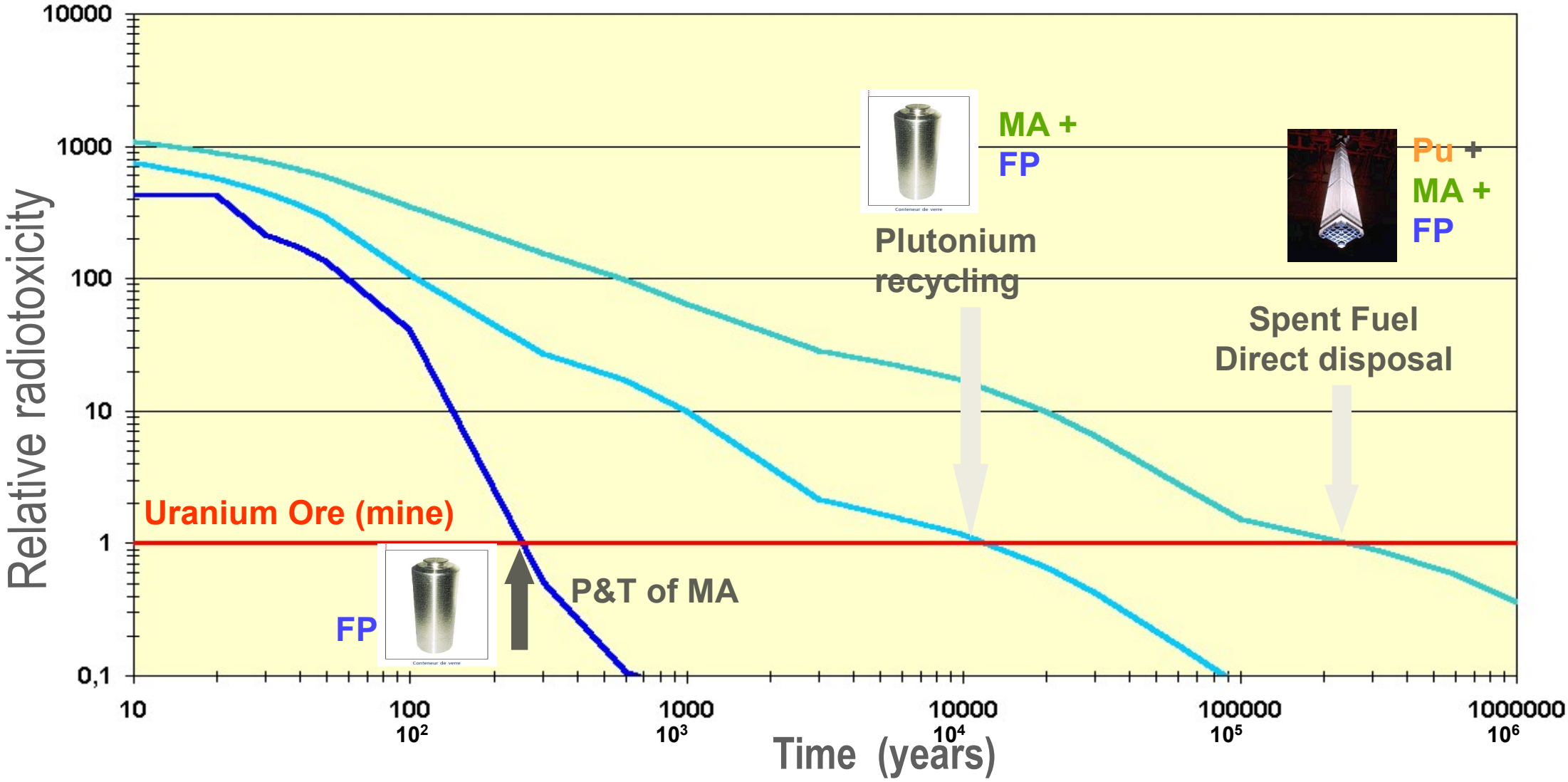
Il problema rifiuti radioattivi

Figure 4.2: Waste generation comparison – yearly production of waste in the European Union

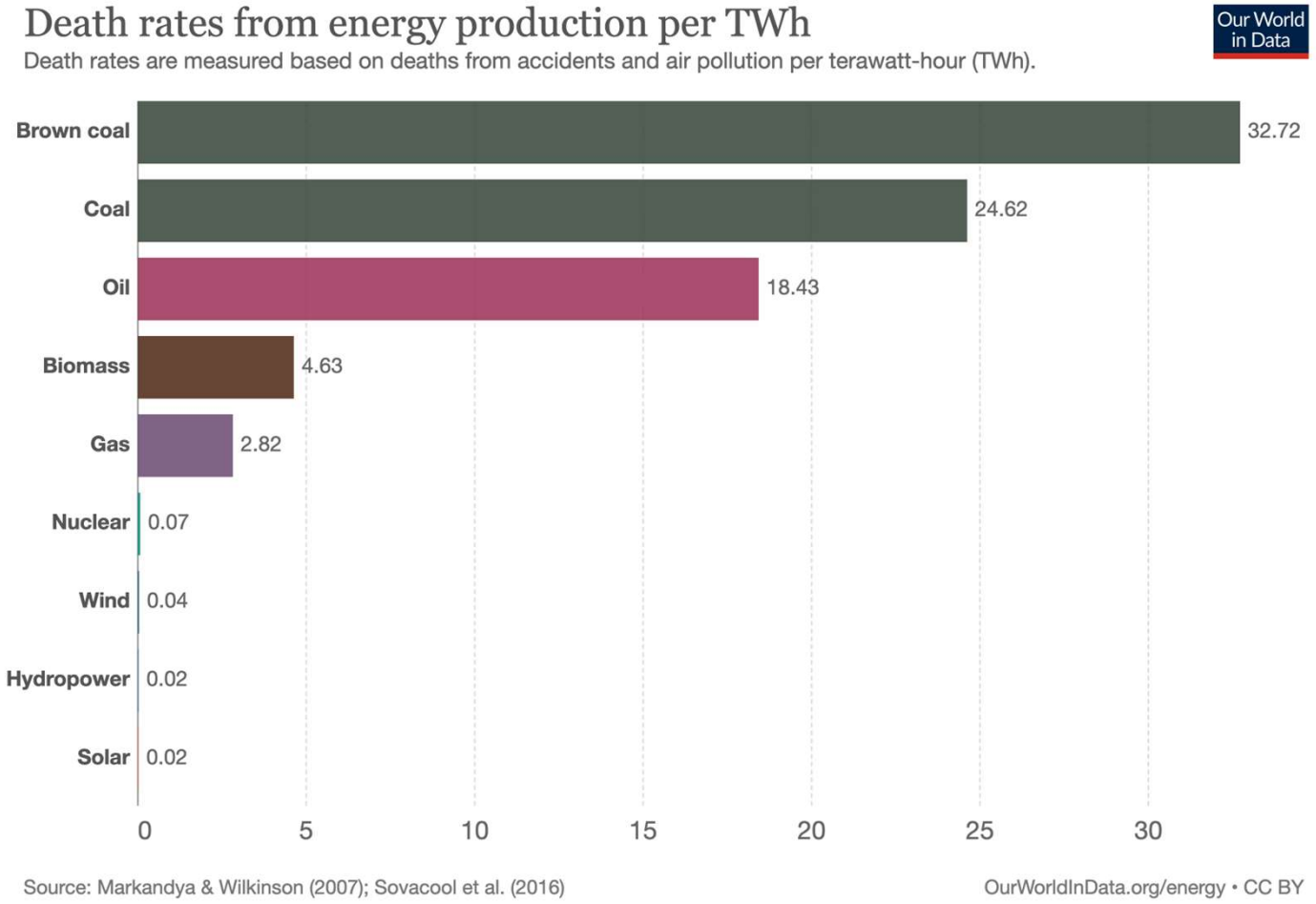


Source: *Nuclear and Renewable Energies* (Rome: Accademia Nazionale dei Lincei, 2000), updated with data from the European Commission, *Radioactive Waste Management in the European Union* (Brussels: EC, 1998).

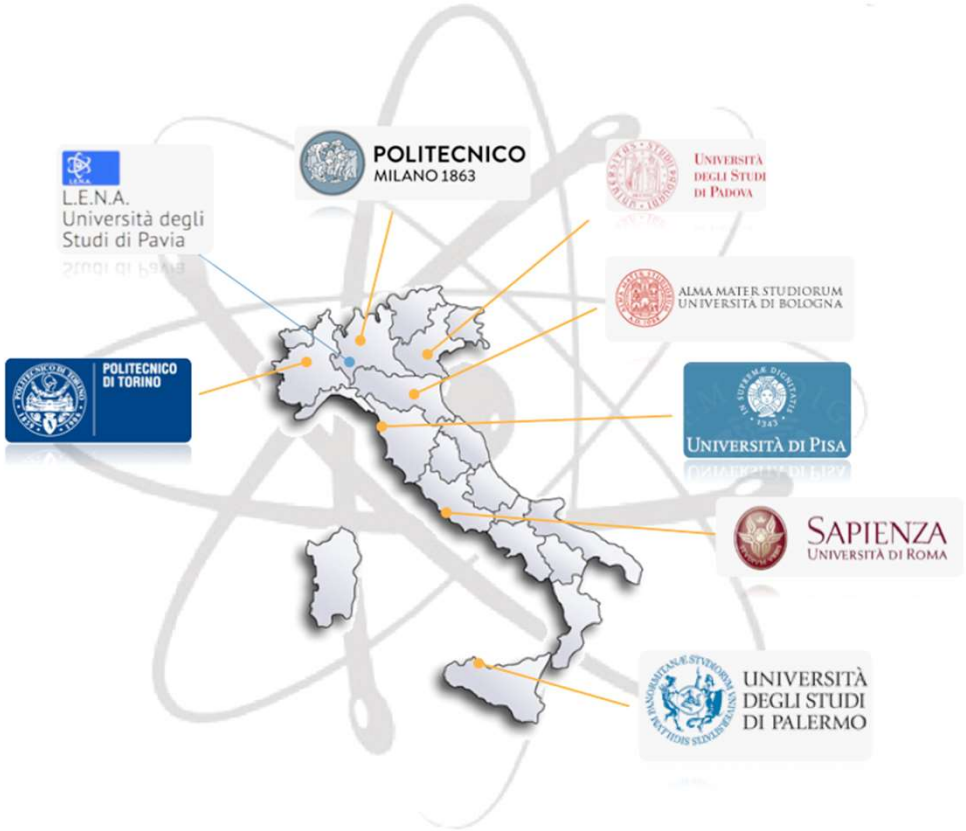
«From BREEDERS to BURNERS»



Il problema sicurezza



CIRTEN: le università «nucleari» italiane



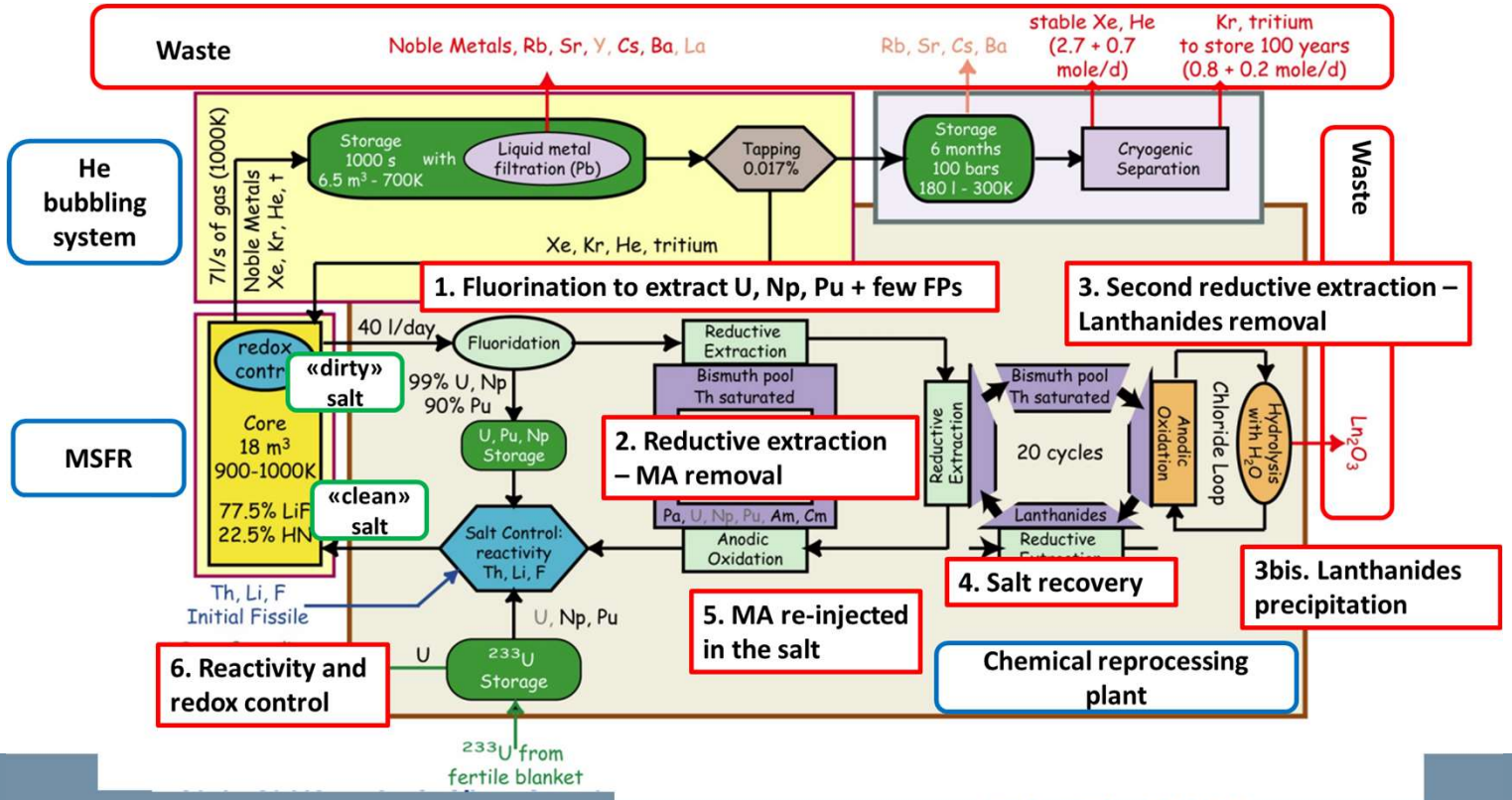
***CIRTEN** is the Consortium of the Italian Universities involved **in nuclear science and technology research** activities, and where **educational programmes** (MSc, PhD) on nuclear engineering are offered to the young generations*

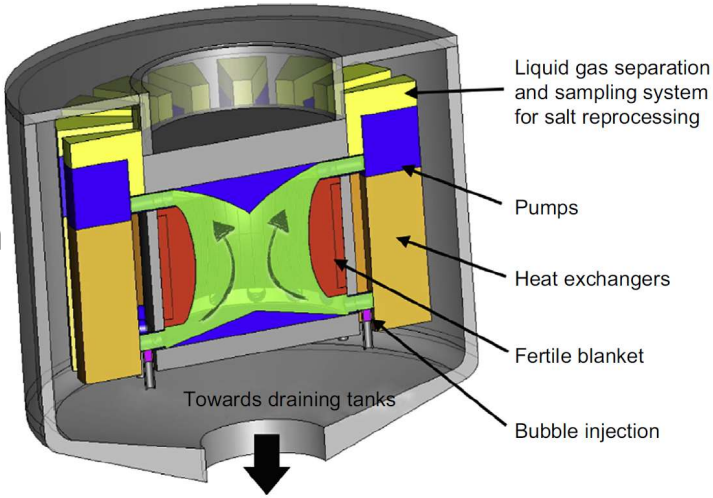
- CIRTEN has been founded in **1994**, joining the competences and the history of Universities active in the nuclear engineering area **since the early '50s**
- In the land of Enrico Fermi, **researchers, professors and young students** are working together to renovate and to transfer knowledge on nuclear technology and its applications

CIRTEN is a proud Founding Member of **ENEN** Association, the European Nuclear Education Network, and of the **World Nuclear University**

Molten Salt Fast Reactor

. **Liquid fuel**: Molten fluoride (or chloride) acting both as fuel and coolant
. **Thorium cycle:** closed cycle with U233 production
. **Fast spectrum**
. **Online reprocessing:** On-site chemical plant and helium bubbling system





Fuel is extracted and reprocessed:

. Major and minor actinides are extracted (1 & 2) to be reused in the fuel, with the addition of fissile from blanket (5 & 6)
. Lanthanides (3), noble metals, Xe, Kr, He, tritium are extracted representing the waste