Nuclear Energy and Nuclear Proliferation

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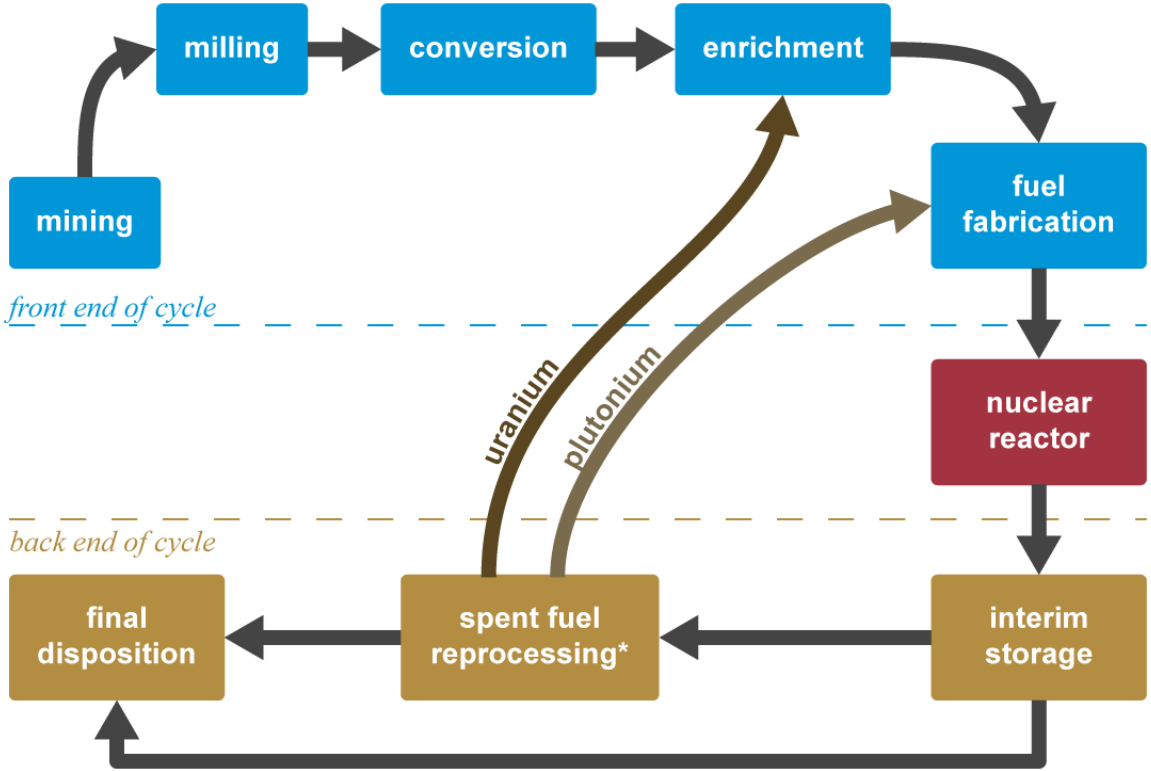
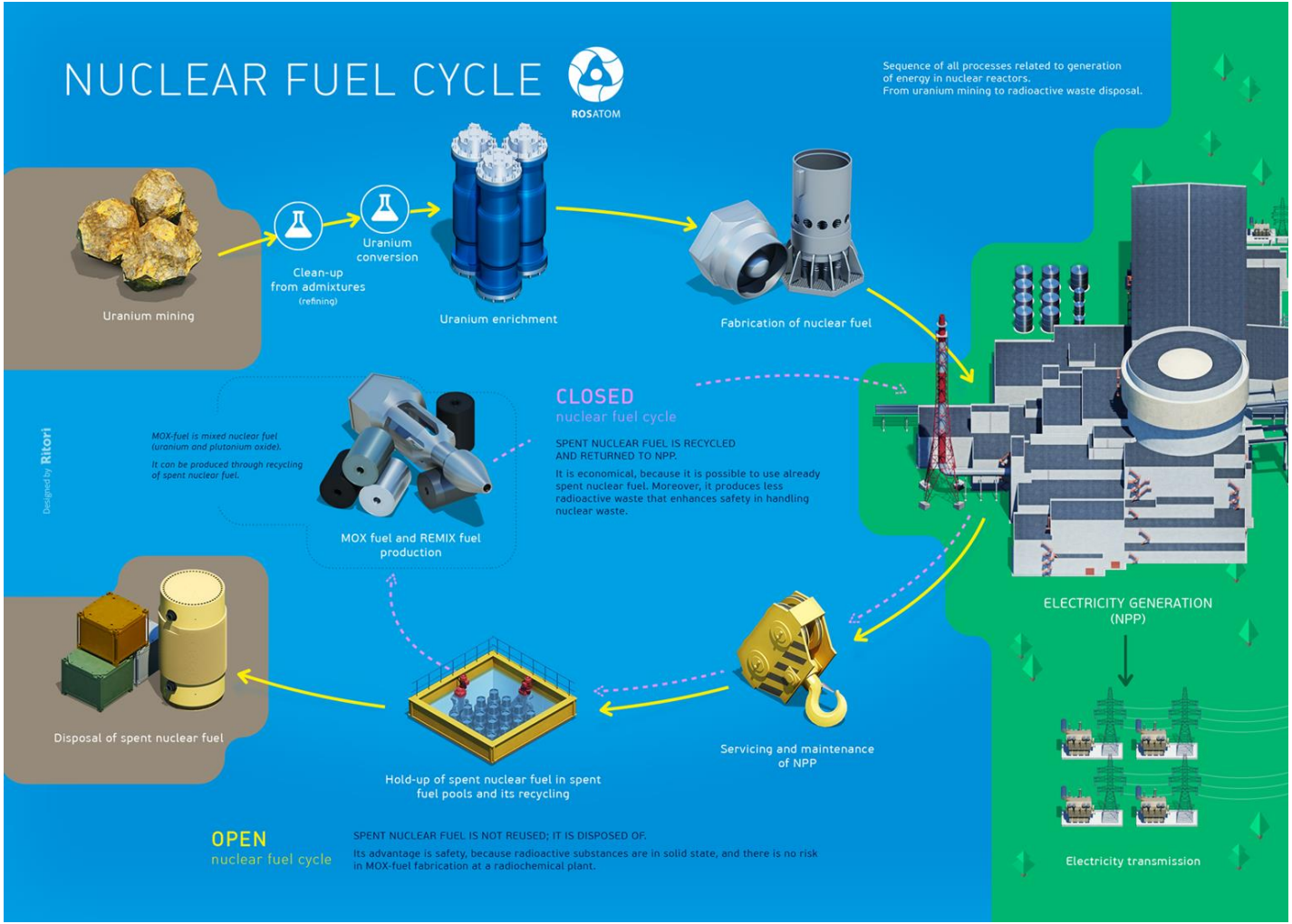
ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

UNIVERSITY OF PIRAEUS

Nuclear fuel cycle

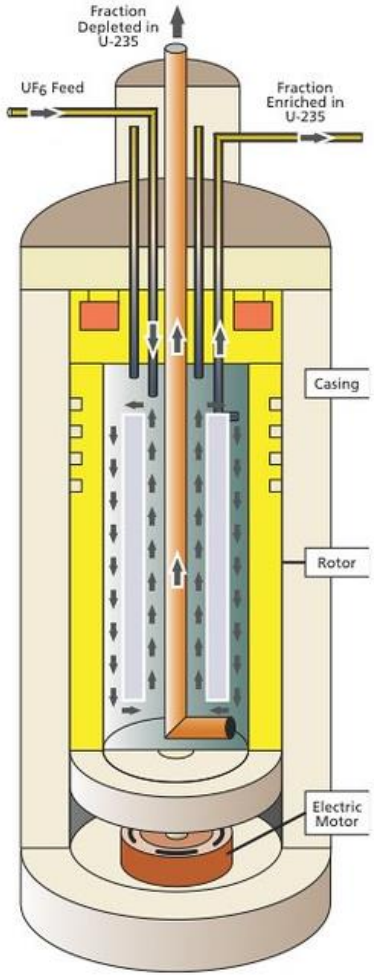


**Spent fuel reprocessing* is omitted from the cycle in most countries, including the United States.


NUCLEAR FUEL CYCLE
ROSATOM
Sequence of all processes related to generation of energy in nuclear reactors. From uranium mining to radioactive waste disposal.
Uranium mining
Clean-up from admixtures (refining)
Uranium conversion
Uranium enrichment
Fabrication of nuclear fuel
ELECTRICITY GENERATION (NPP)
Electricity transmission
Servicing and maintenance of NPP
Hold-up of spent nuclear fuel in spent fuel pools and its recycling
Disposal of spent nuclear fuel
MOX fuel and REMIX fuel production
MOX-fuel is mixed nuclear fuel (uranium and plutonium oxide).
It can be produced through recycling of spent nuclear fuel.
CLOSED
nuclear fuel cycle
SPENT NUCLEAR FUEL IS RECYCLED AND RETURNED TO NPP.
It is economical, because it is possible to use already spent nuclear fuel. Moreover, it produces less radioactive waste that enhances safety in handling nuclear waste.
OPEN
nuclear fuel cycle
SPENT NUCLEAR FUEL IS NOT REUSED; IT IS DISPOSED OF.
Its advantage is safety, because radioactive substances are in solid state, and there is no risk in MOX-fuel fabrication at a radiochemical plant.
Designed by Ritori

Gas Centrifuge Process

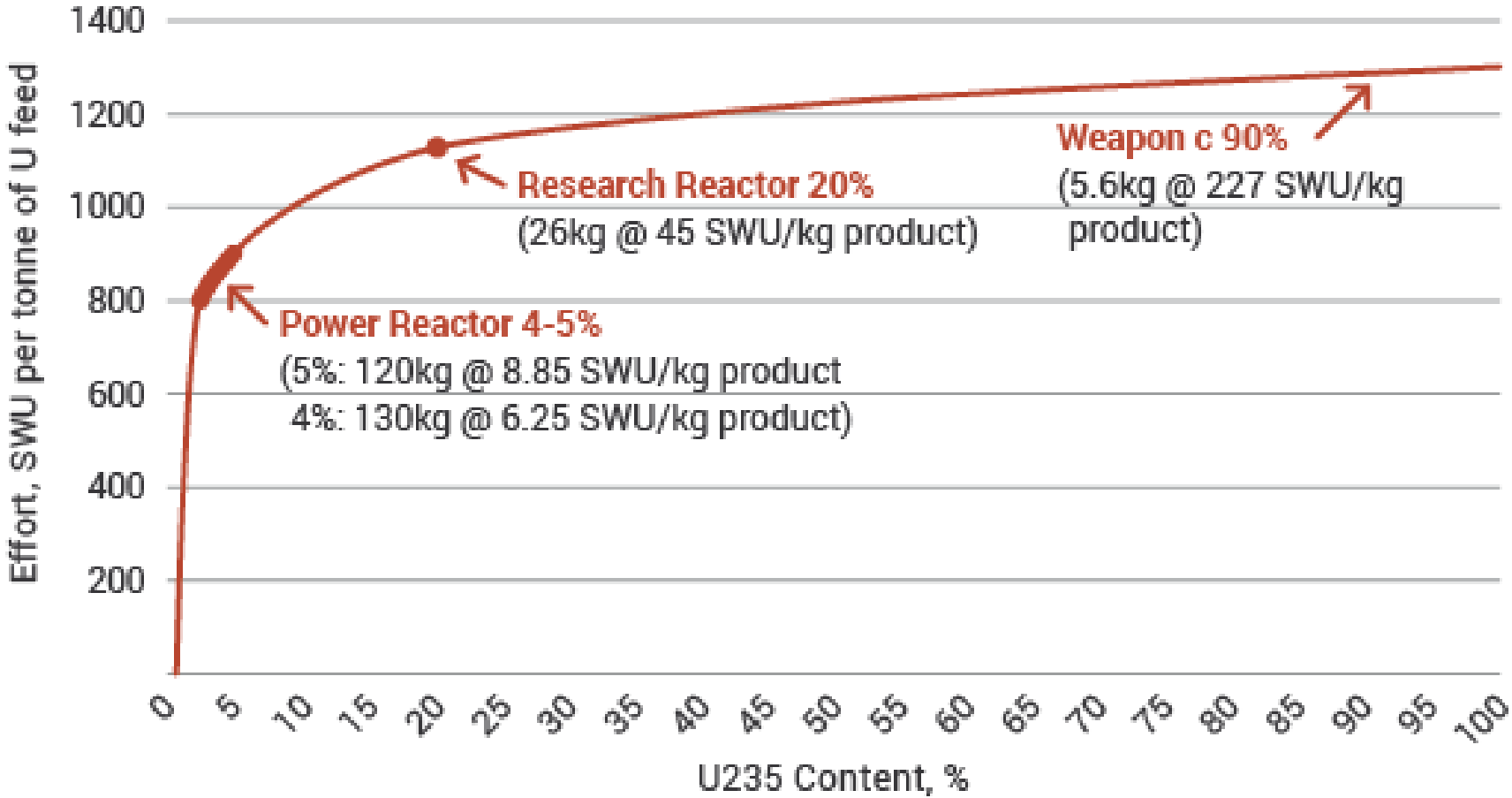
Gas centrifuge process
The gas centrifuge process uses many rotating cylinders that are connected in long lines. Gas is placed in the cylinder, which spins at a high speed, creating a strong centrifugal force. Heavier gas molecules move to the cylinder wall, while lighter molecules collect near the center. The stream, now slightly enriched, is fed into the next cylinder. The depleted stream is recycled back into the previous cylinder.



U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

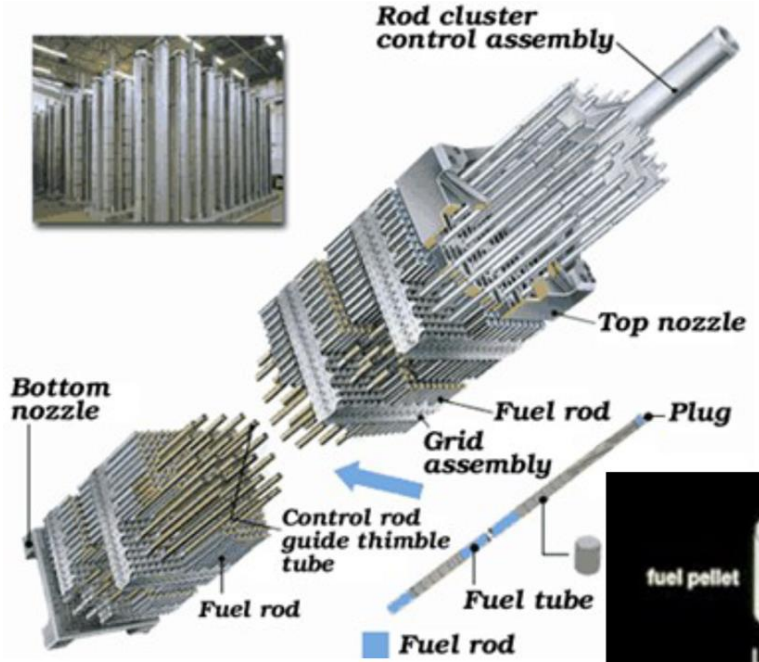
As of July 2018

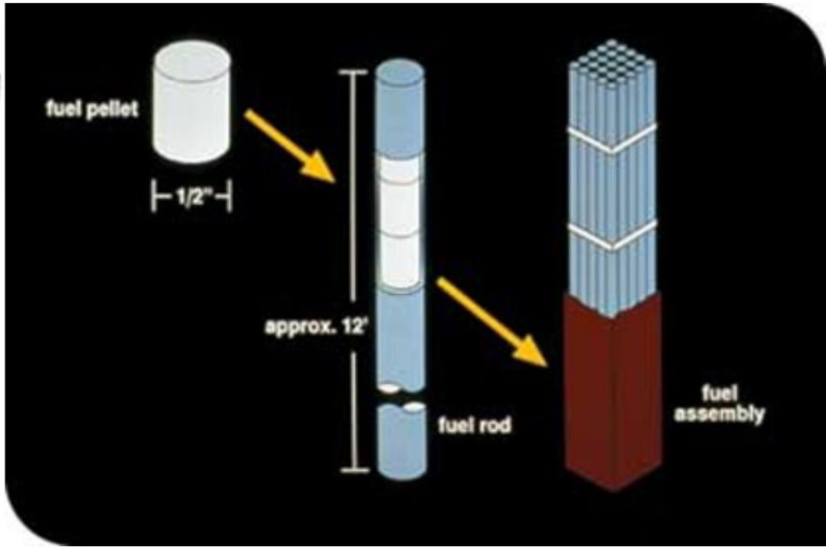
Uranium Enrichment and Uses



The large Georges Besse I enrichment plant at Tricastin in France (beyond cooling towers) was shut down in 2012.
Most of the output from the nuclear power plant (4x915MWe net) was used to power the enrichment facility.

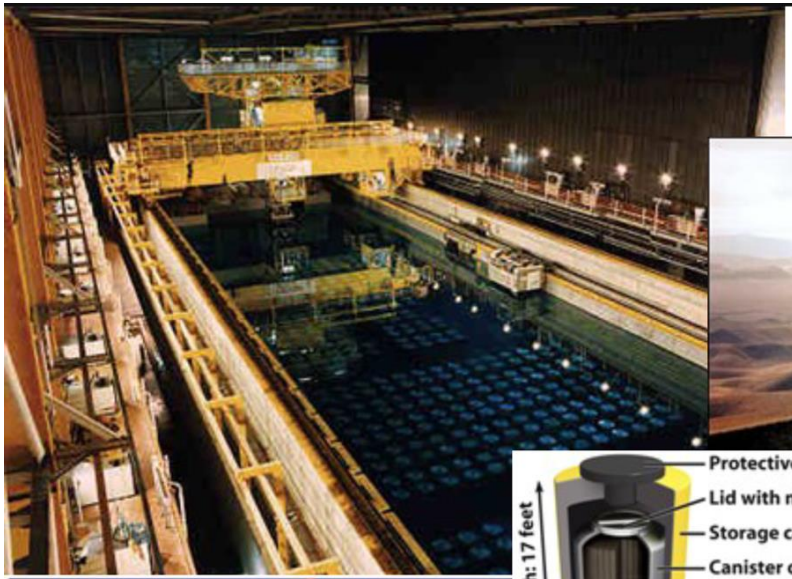
Fuel Assembly





A fuel assembly consists of a square array of 179 to 264 fuel rods, and 121 to 193 fuel assemblies are loaded into an individual reactor - numbers vary greatly

Spent Fuel Storage



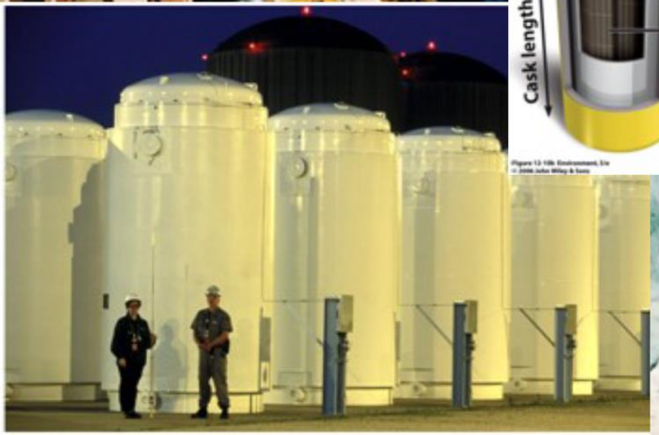
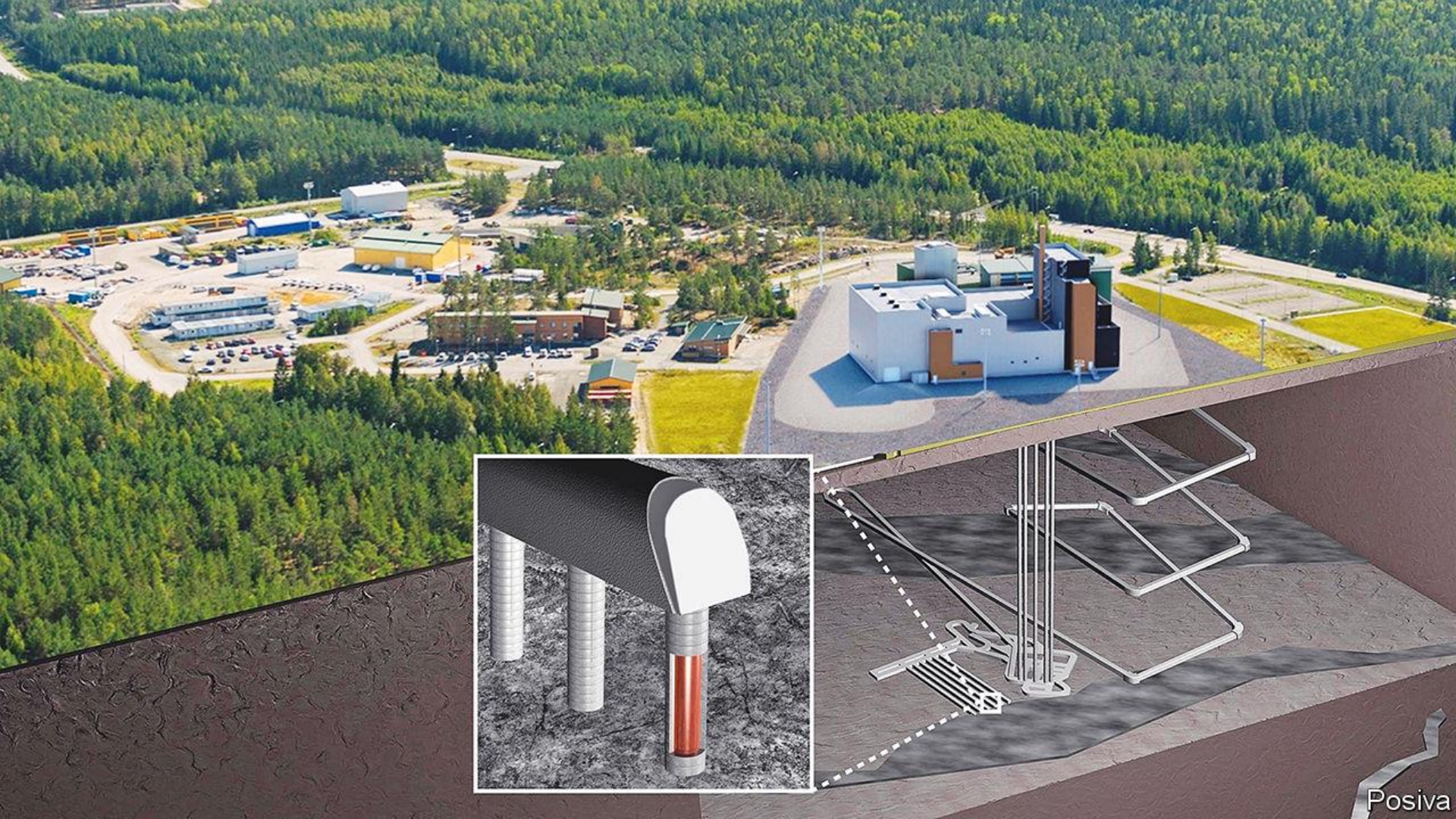
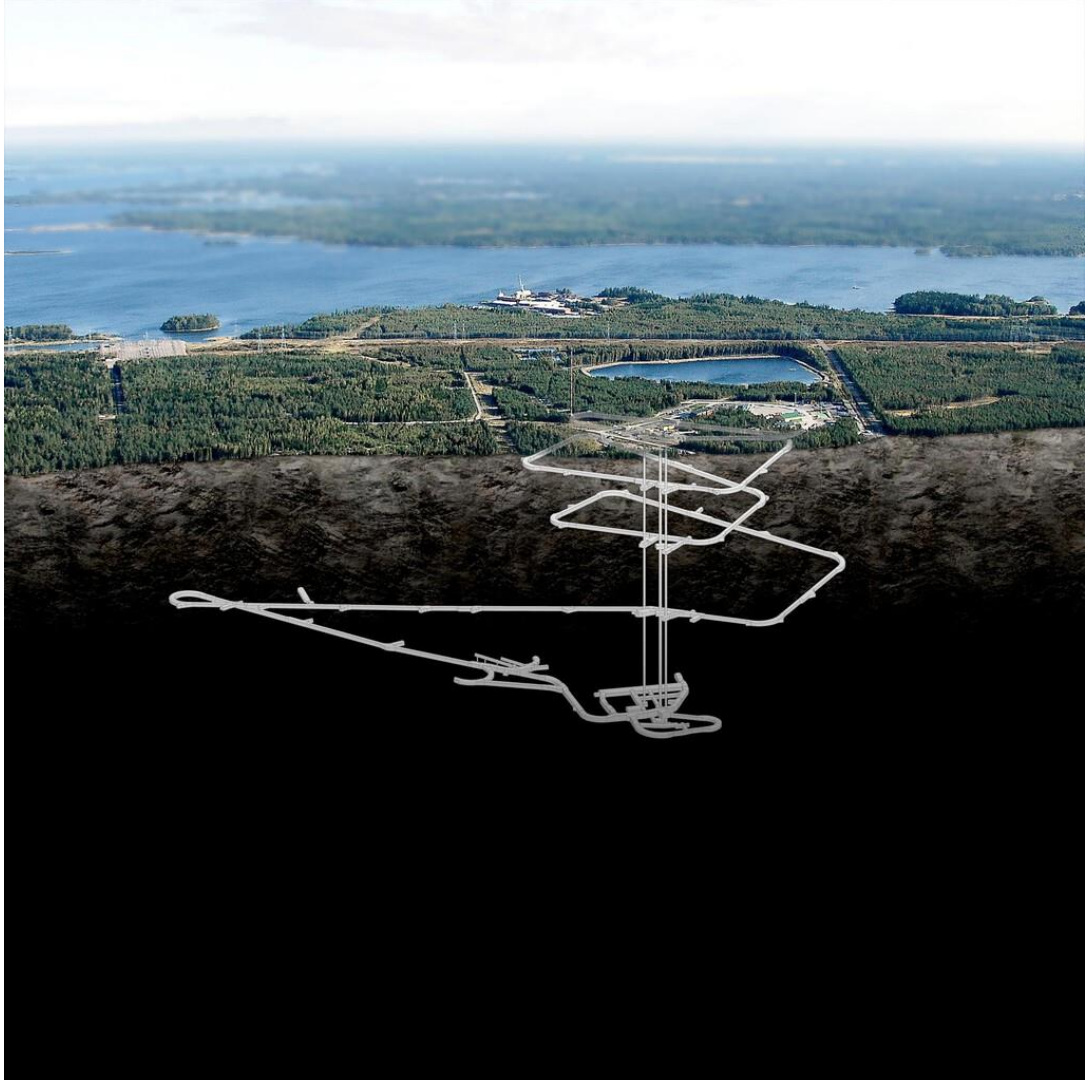
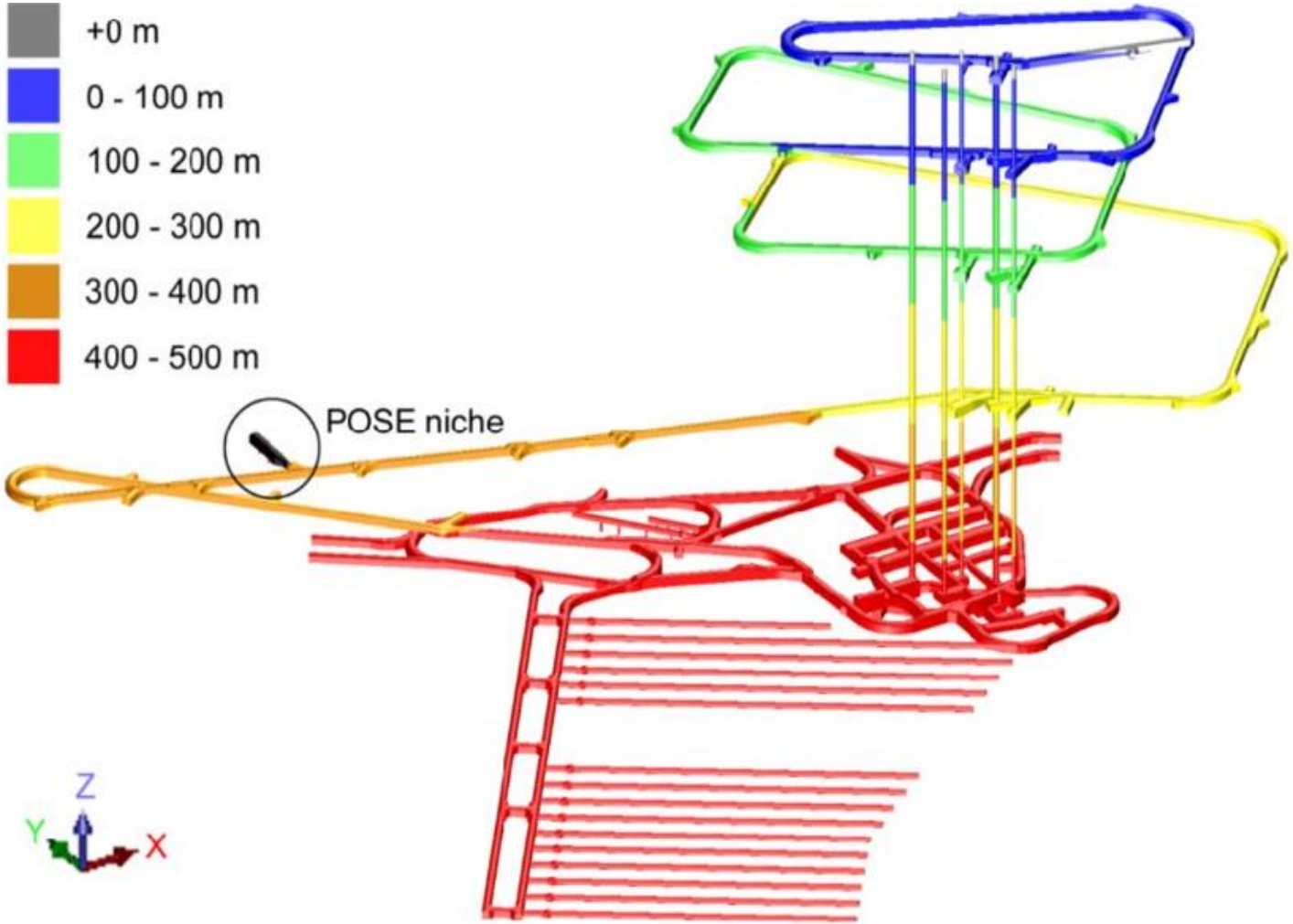
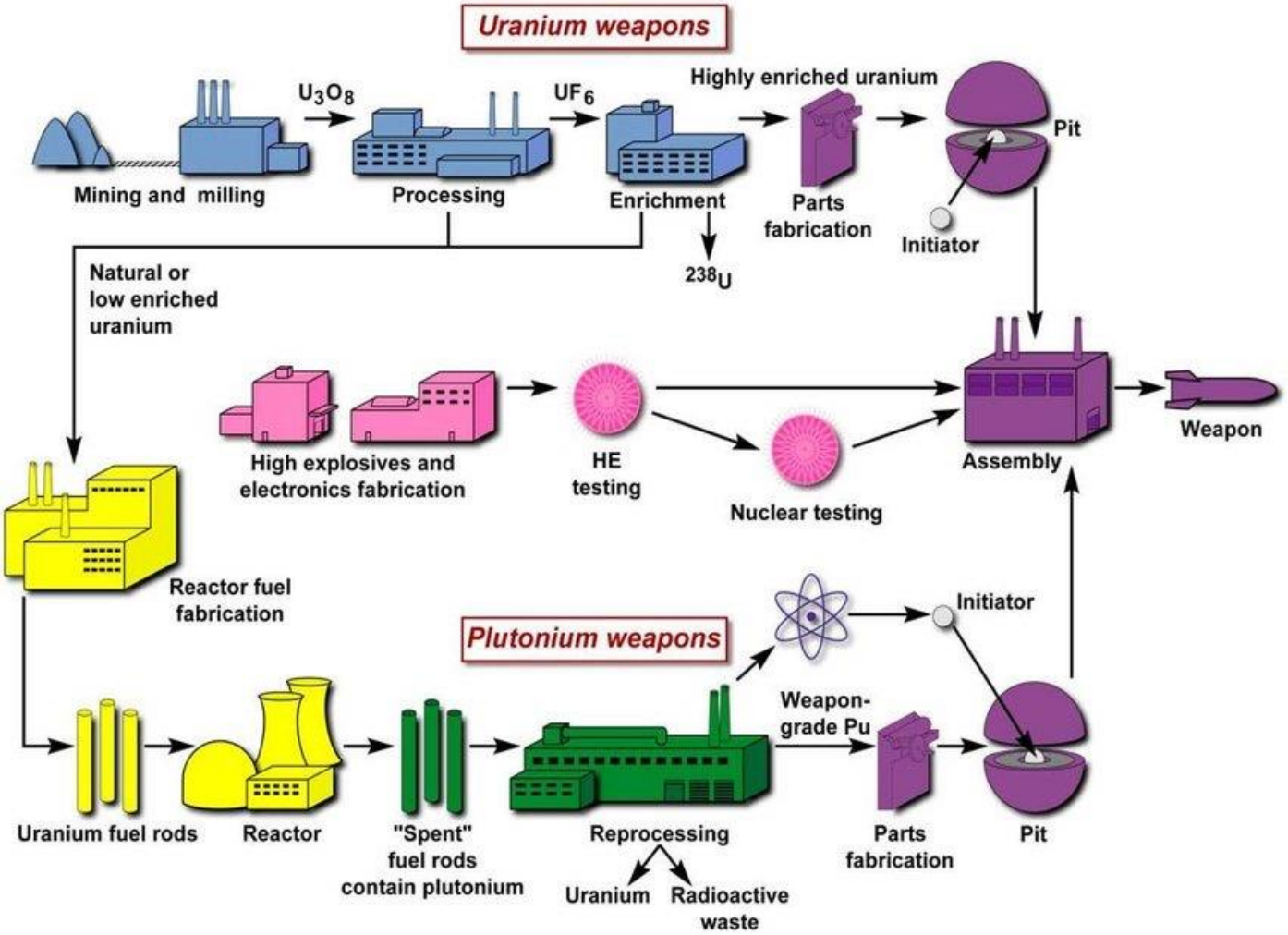


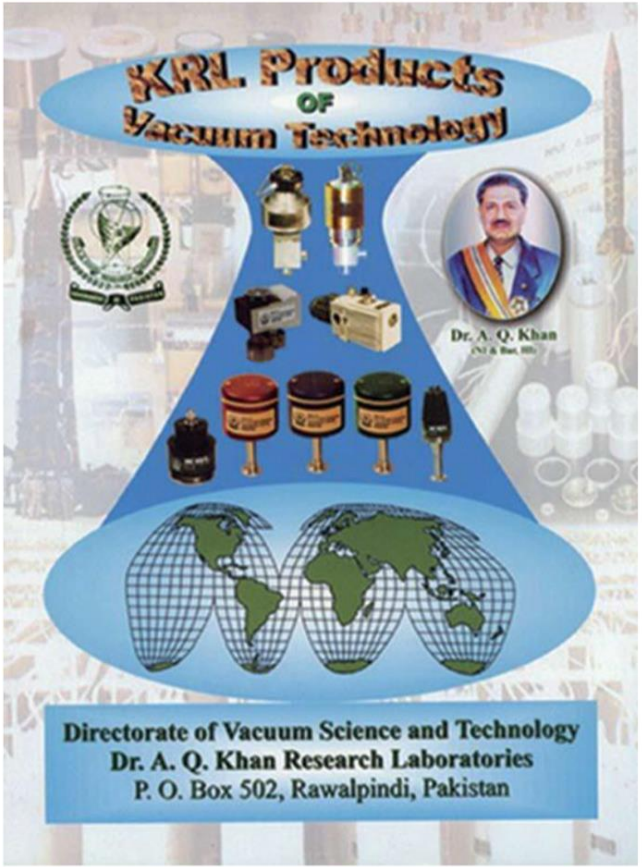
Figure 12-10a Environment, 5/e


Posiva




+0 m
0 - 100 m
100 - 200 m
200 - 300 m
300 - 400 m
400 - 500 m
POSE niche
Z
Y
X


Uranium weapons
U_3O_8
UF_6
Highly enriched uranium
Pit
Mining and milling
Processing
Enrichment
Parts fabrication
Initiator
^{238}U
Natural or low enriched uranium
High explosives and electronics fabrication
HE testing
Nuclear testing
Assembly
Weapon
Reactor fuel fabrication
Plutonium weapons
Initiator
Weapon-grade Pu
Uranium fuel rods
Reactor
"Spent" fuel rods contain plutonium
Reprocessing
Parts fabrication
Pit
Uranium
Radioactive waste



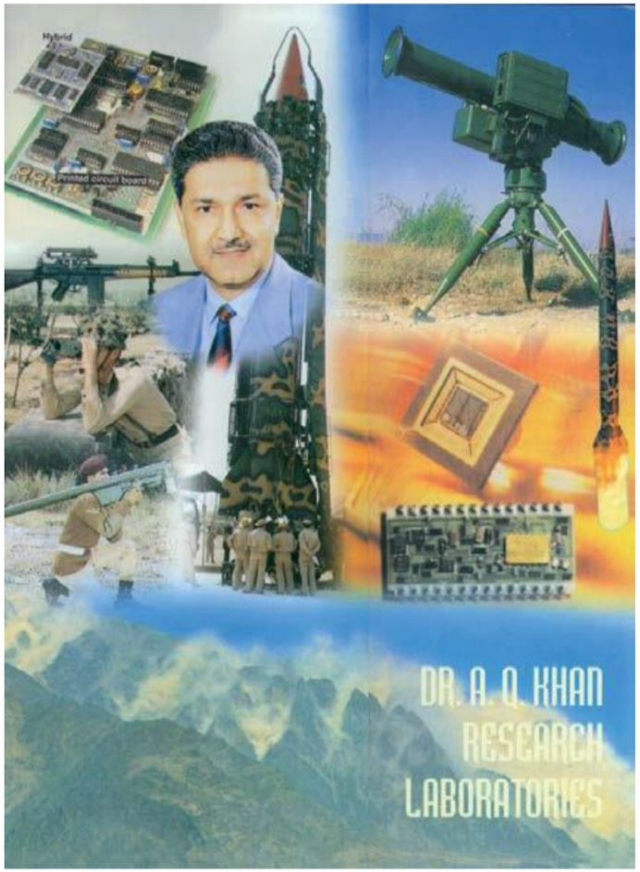


Figure 1: KRL Brochure distributed at 2000 Karachi arms fair (left) and KRL Brochure (right)

The Nuclear Network and Pakistan's Atomic Hero

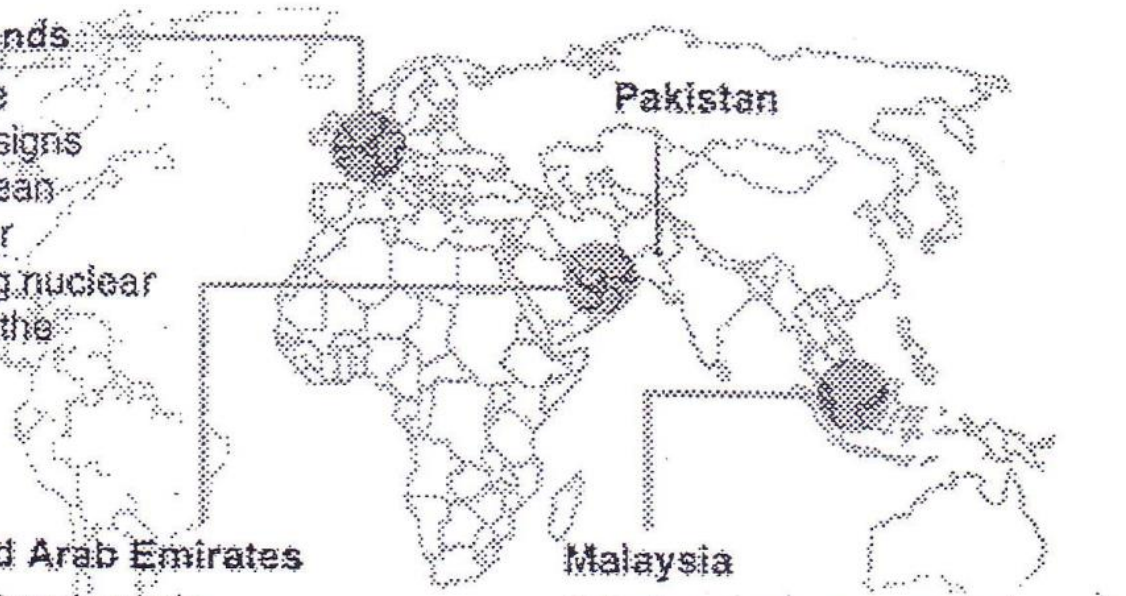
A founder of Pakistan's nuclear weapons program, Dr. Abdul Qadeer Khan (right), is the leading figure behind a global nuclear black market that continued to operate until last fall, American, European and Pakistani officials say. Dr. Khan's network sent nuclear weapons technology to Iran, North Korea and Libya.

Associated Press

DESIGNS

The Netherlands

Dr. Khan stole centrifuge designs from a European consortium for manufacturing nuclear equipment in the 1970's.



MIDDLEMEN

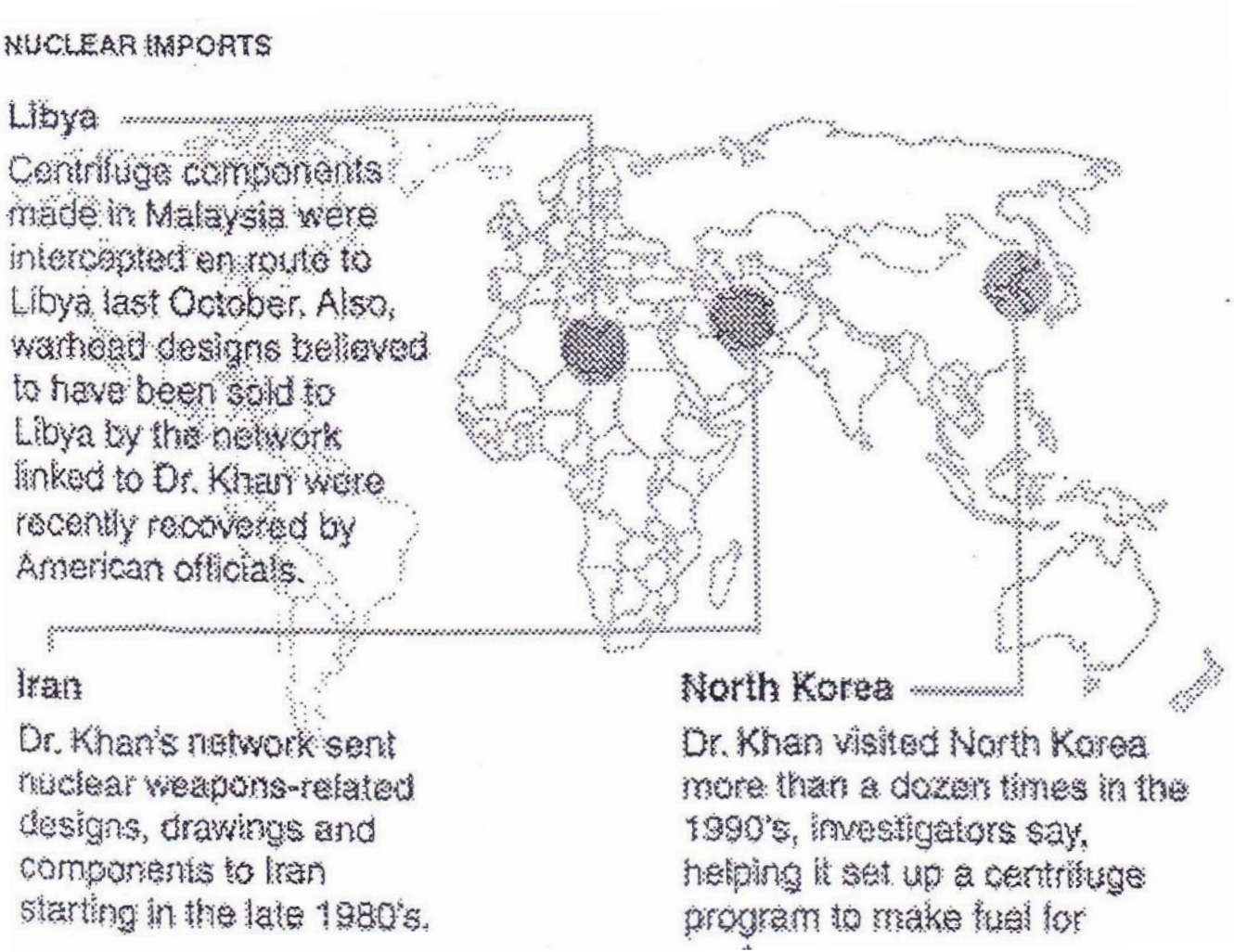
Dubai, United Arab Emirates

Dr. Khan's network made shipments of nuclear hardware through Dubai, investigators say. Additionally, centrifuge parts were shipped here from a factory in Malaysia en route to Libya.

Malaysia

A factory was set up here to fulfill an order from one of Dr. Khan's middlemen. Based on Pakistani designs, the factory made centrifuge components that were shipped to Dubai and from there to Libya.

NUCLEAR IMPORTS



Libya

Centrifuge components made in Malaysia were intercepted en route to Libya last October. Also, warhead designs believed to have been sold to Libya by the network linked to Dr. Khan were recently recovered by American officials.

Iran

Dr. Khan's network sent nuclear weapons-related designs, drawings and components to Iran starting in the late 1980's.

North Korea

Dr. Khan visited North Korea more than a dozen times in the 1990's, investigators say, helping it set up a centrifuge program to make fuel for

TABLE 2.2. Typology of the Strategies of Nuclear Proliferation

Strategy	Intended Outcome
Varieties of Hedging	Develop the option for a weapon
Sprinting	Weaponize as quickly as possible
Sheltered Pursuit	Weaponize before abandonment by patron
Hiding	Weaponize without being discovered

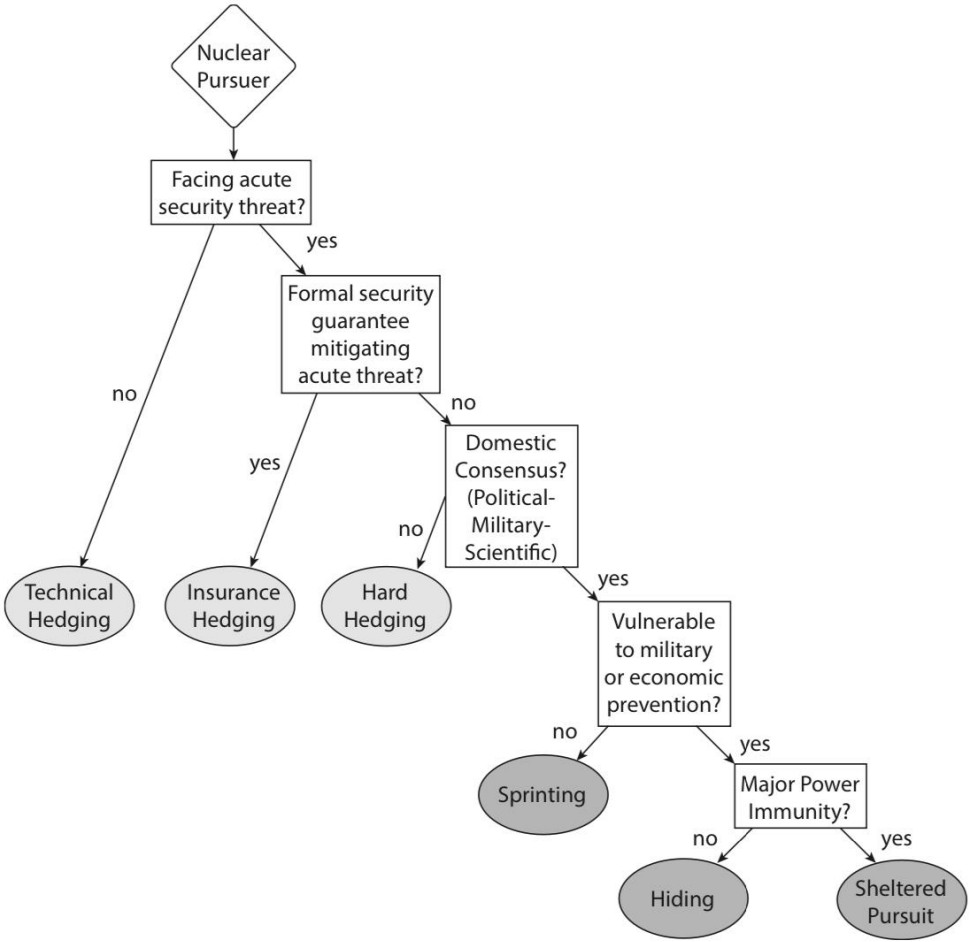
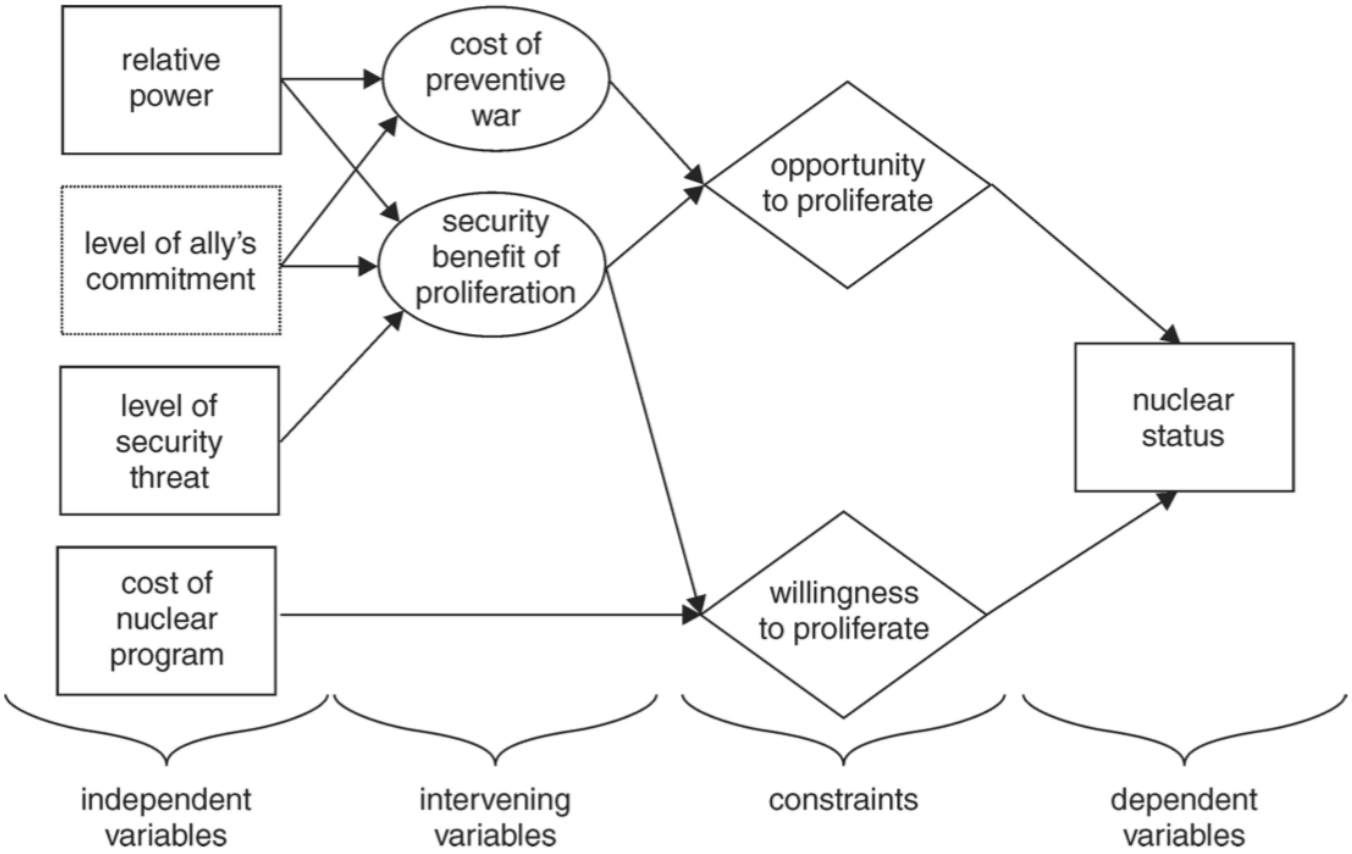
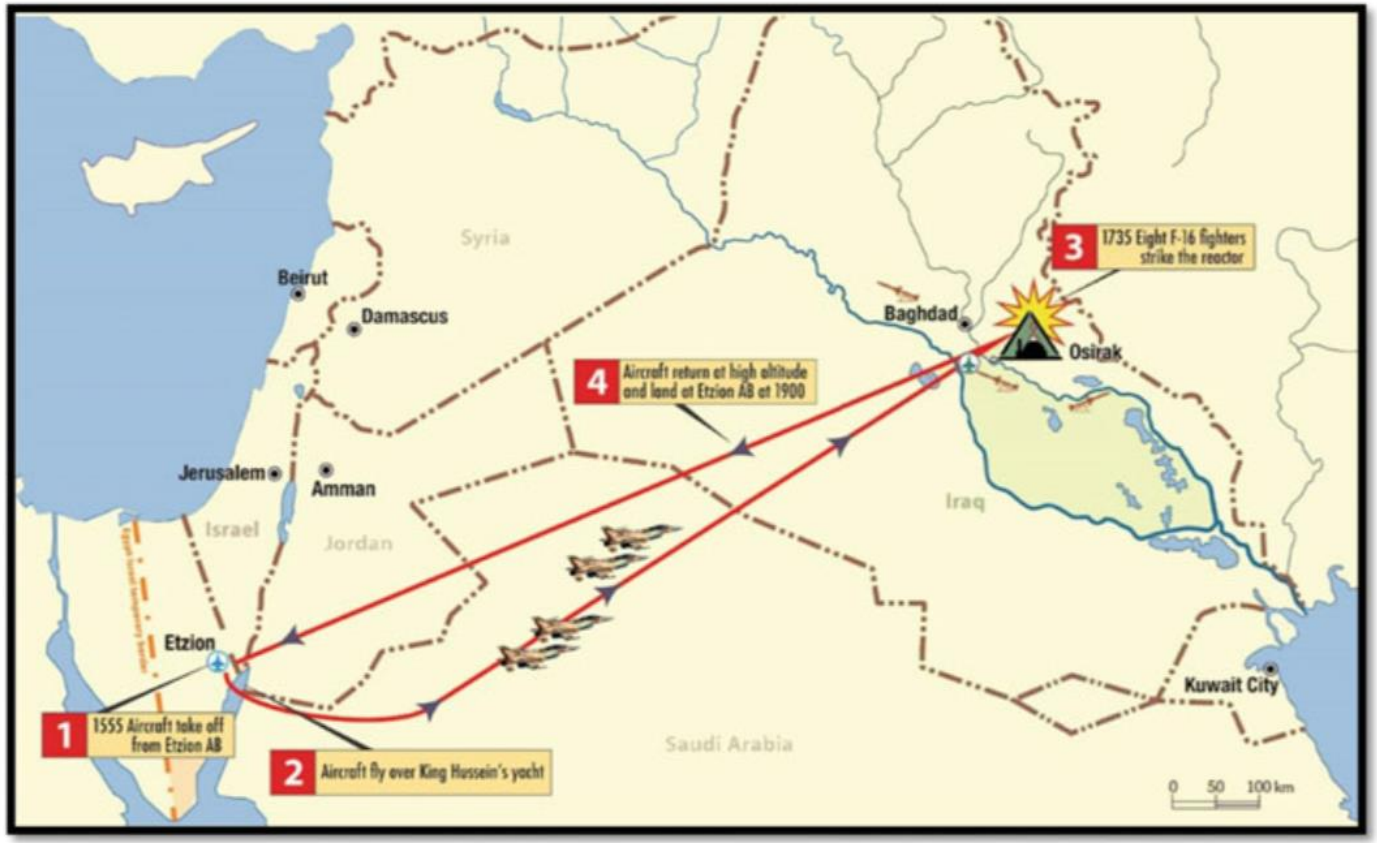


FIGURE 2.1. Proliferation Strategy Theory.

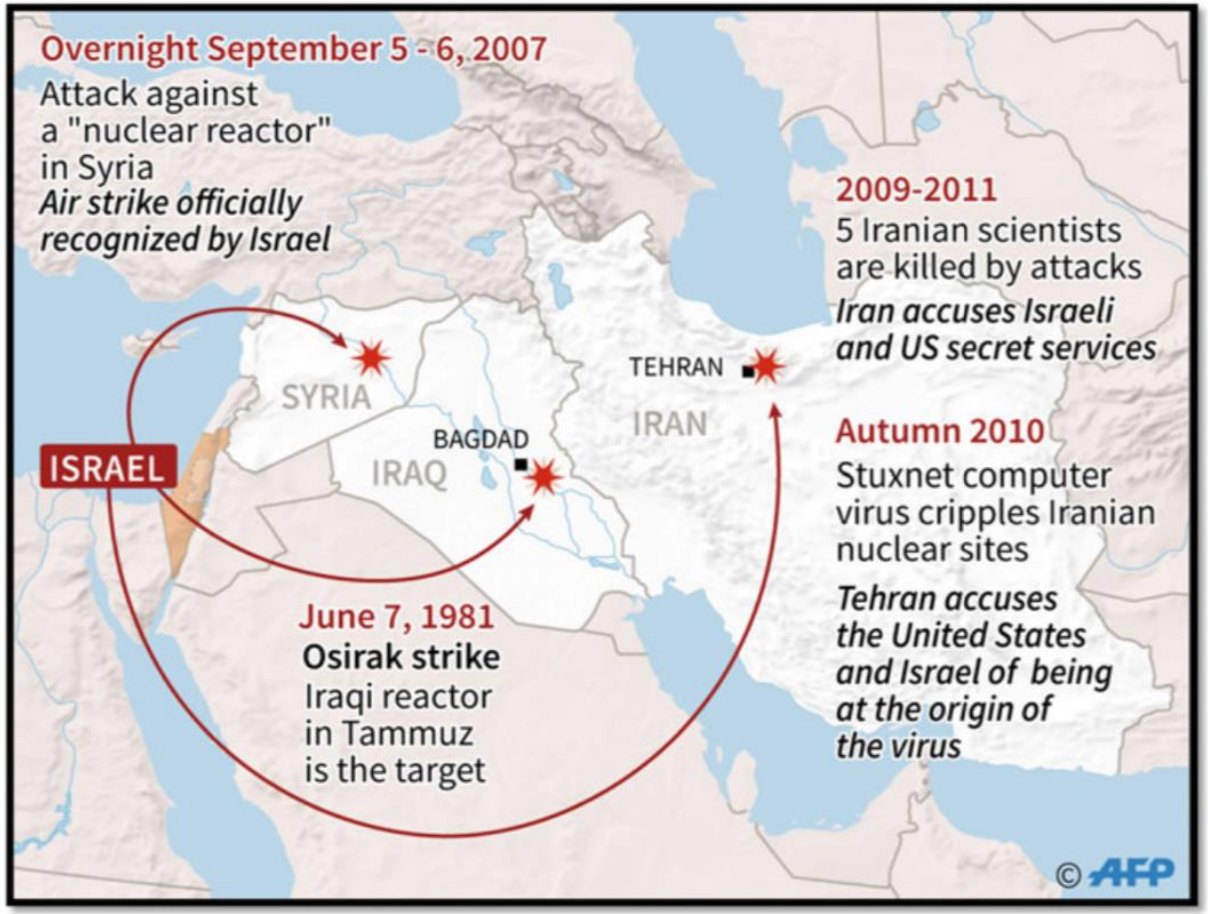
Figure 1. The Strategic Logic of Nuclear Proliferation



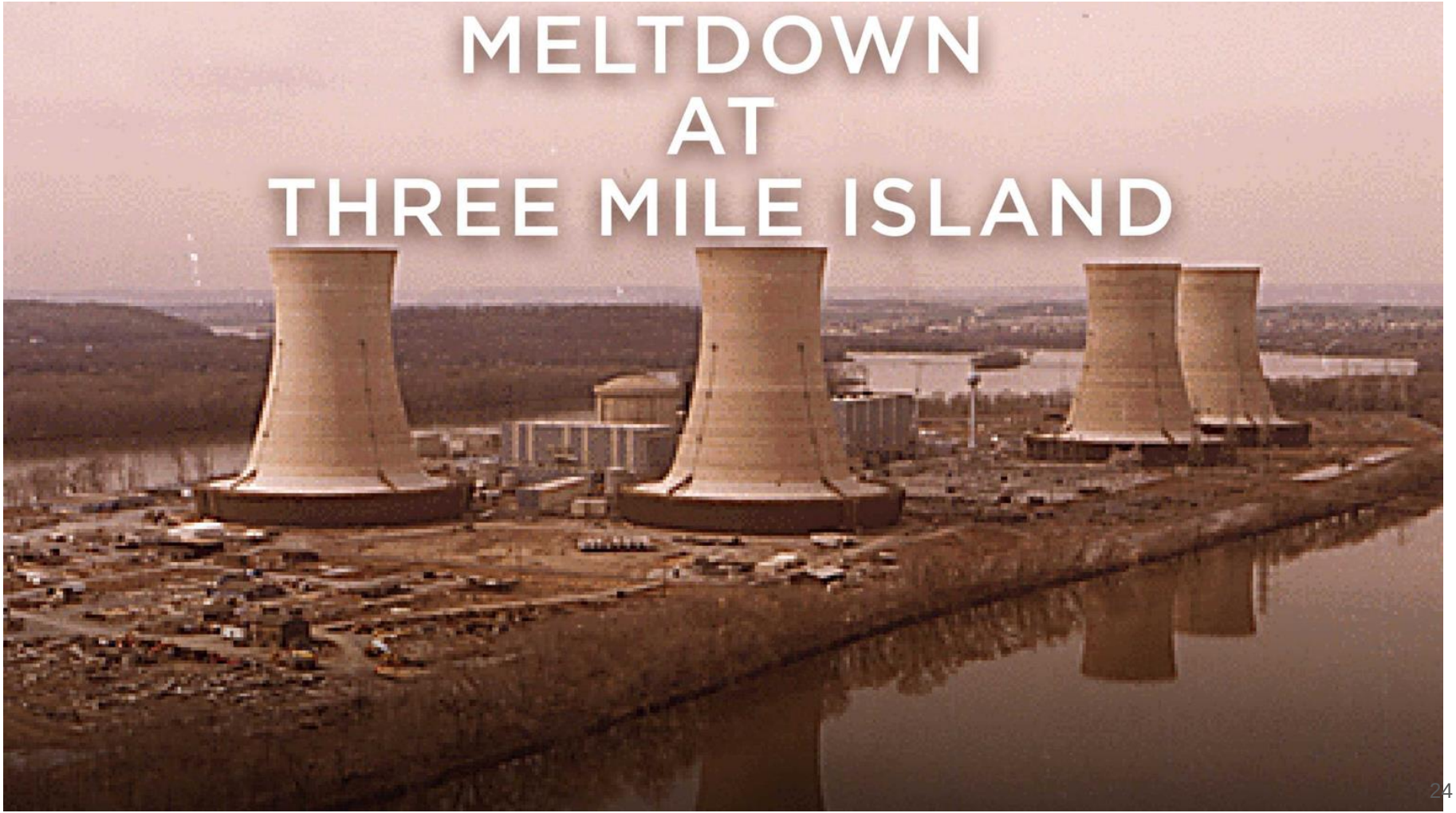
NOTE: The dotted lines refer to the effect of alliances on proliferation.

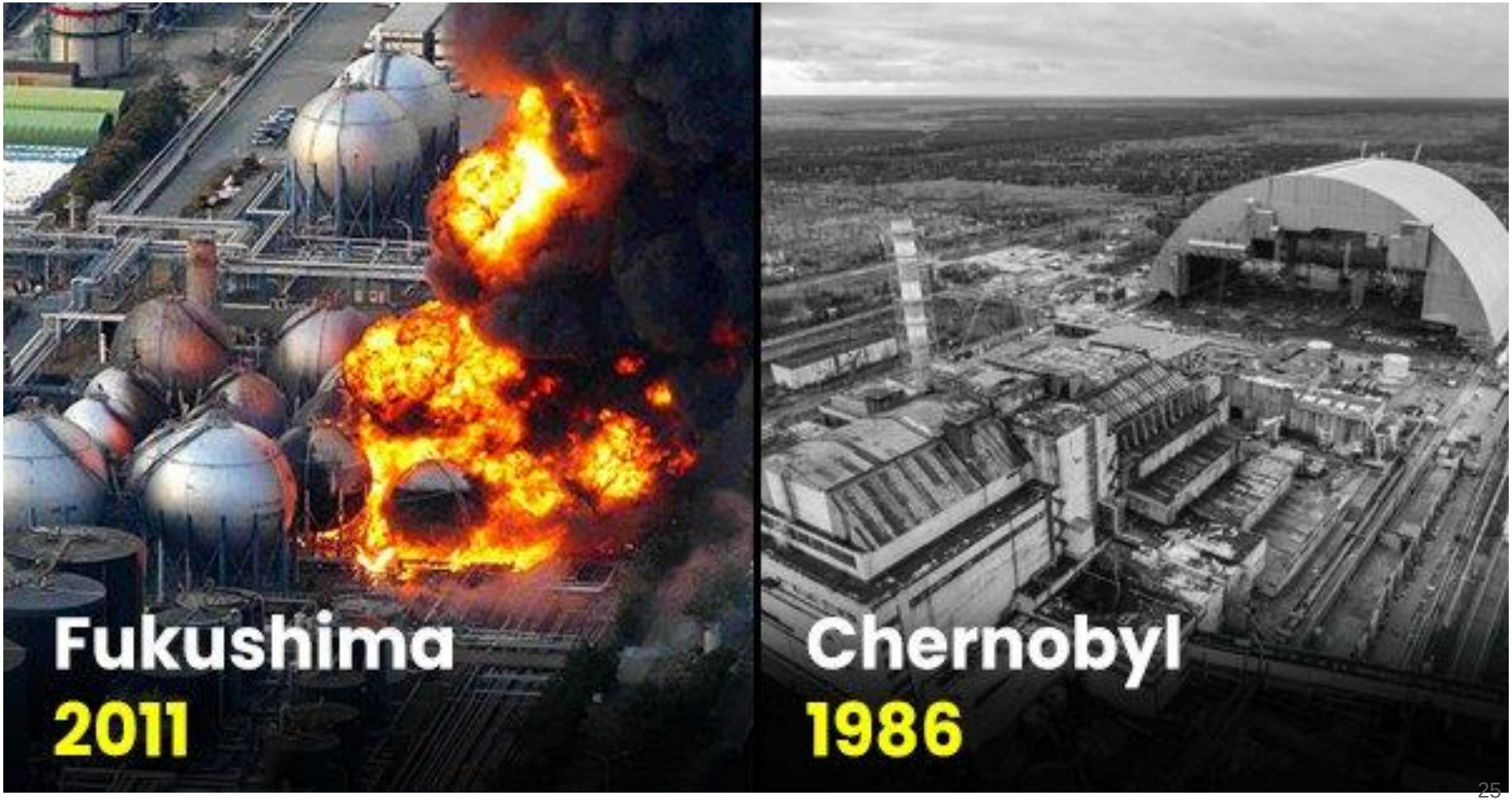


Map 7 Israeli Raid on Iraq's Osirak Nuclear Reactor (*Source*: Reprint courtesy of Air Force Magazine/Map: Tsahi Ben-Ami)



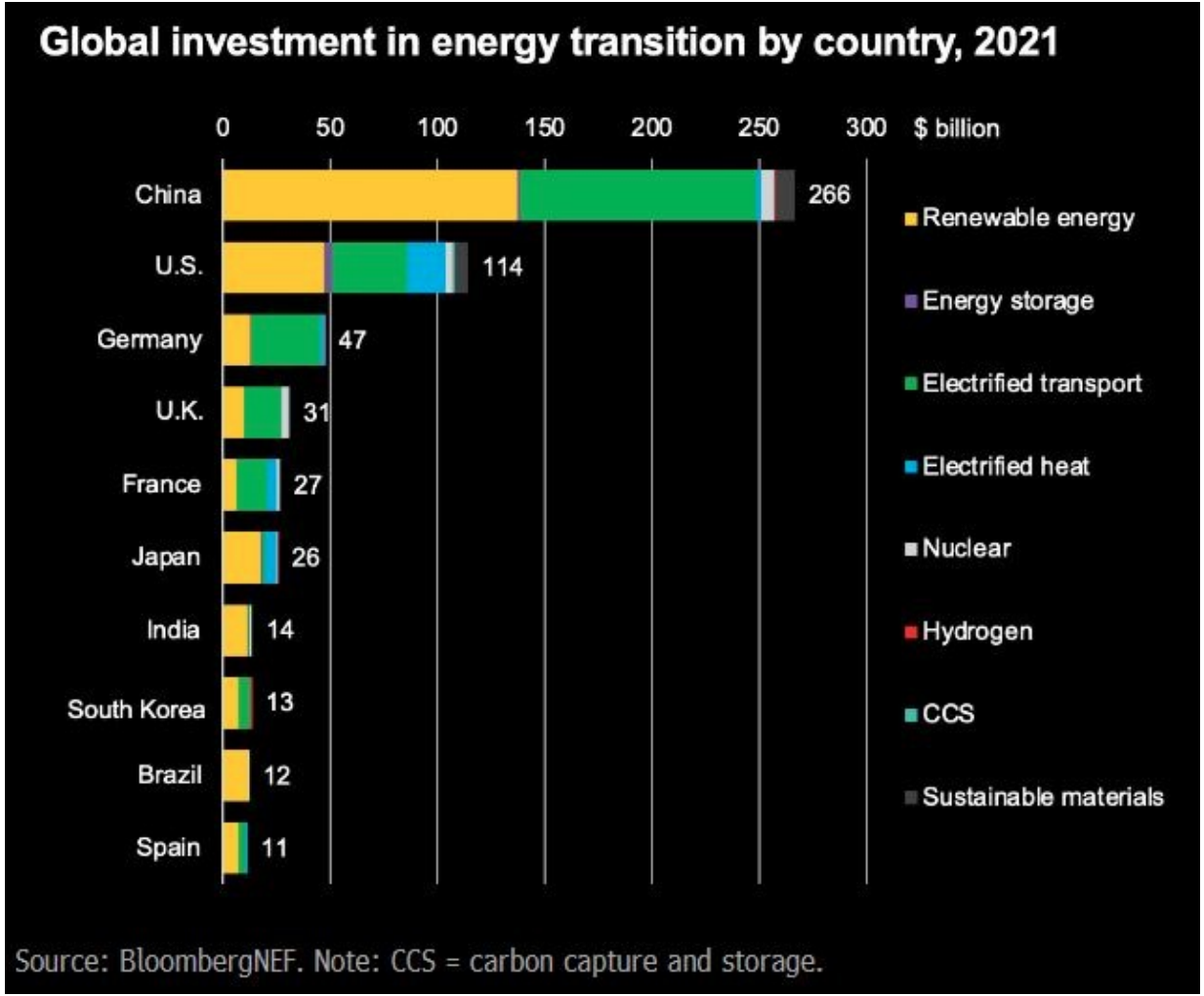
Map 8 Nuclear Facility Strikes Attributed to Israel (*Source*: Courtesy of AFP)


MELTDOWN
AT
THREE MILE ISLAND


Fukushima
2011
Chernobyl
1986

Rosatom marketing: Build, Own, Operate


AKKUYU NÜKLEER
İçtaş inşaat
İçtaş inş
AKKUYU NÜKLEER


Global investment in energy transition by country, 2021
0
50
100
150
200
250
300
$ billion
China
266
U.S.
114
Germany
47
U.K.
31
France
27
Japan
26
India
14
South Korea
13
Brazil
12
Spain
11
Renewable energy
Energy storage
Electrified transport
Electrified heat
Nuclear
Hydrogen
CCS
Sustainable materials
Source: BloombergNEF. Note: CCS = carbon capture and storage.

EDF's UK Hinkley Nuclear Costs Balloon as Plant Delayed Anew

- Station could cost as much as £10 billion more than planned
- Unit 1 may not start until 2031 in a worst case scenario

Cranes surround Reactor Unit Two on the construction project for Hinkley Point C nuclear power station. *Photographer: Luke MacGregor/Bloomberg*

LARGE, CONVENTIONAL REACTOR
700+ MW(e)

SMALL MODULAR REACTOR
Up to 300 MW(e)

MICROREACTOR
Up to ~10 MW(e)

What are the advantages?

The economics and business case of SMRs are different from traditional nuclear power plants. SMRs have a range of advantages

Besides contributing to the **decarbonisation** of theEU energy mix, SMRs can help ensuring the **stability of the electric grid** in a system with a higher share of renewables and **increasing electricity demand.**

As they are **smaller** in size, power output and capacity, they need less space and **less cooling water**, but offer greater **flexibility** for site selection than large nuclear plants.

They are modular and can be produced in series, which allows for **production cost efficiency** through economies of scale.

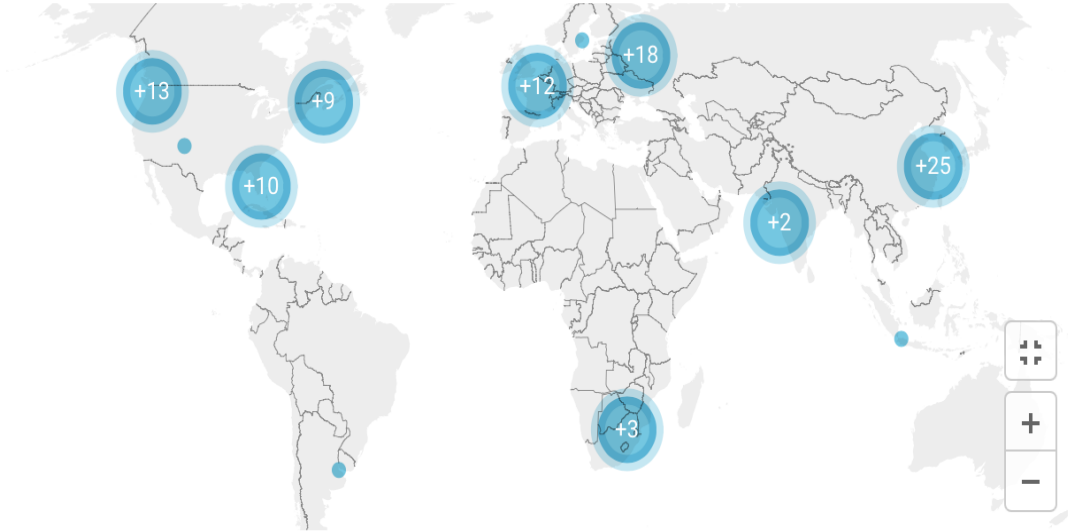
As their systems and components can be **factory-assembled,** they can be **transported as modules** or even whole units to a location, reducing installation costs.

SMRs are well suited to **replace fossil fuels-fired plants,** allowing to retain **high-skilled job opportunities** in areas affected by the closures of such plants.

They are well suited to be **integrated in energy hubs** in combination with other sources of energy and energy vectors, like renewables and hydrogen.

They are adapted to **supply electricity** and additionally capable to supply heat for industrial applications, district heating, as well as for production of hydrogen.

SMR designs in development



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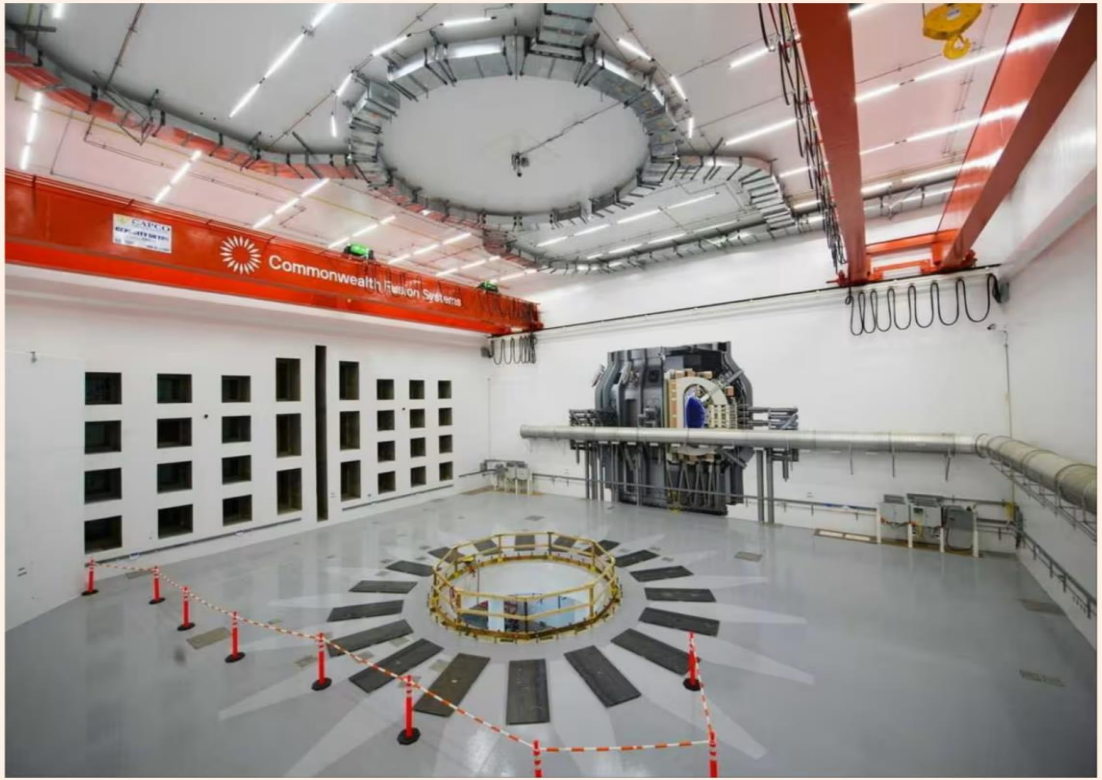
Scientists inch towards holy grail of fusion reactors

Many companies predict commercial viability next decade, but more funding is needed now



The Commonwealth Fusion Systems SPARC project in Massachusetts, which is developing the technology underlying a future fusion power plant

Thank you for your attention!