The Most Important Substance You've Never Heard Of (Probably)

The story of Molybdenum-99

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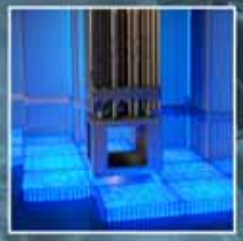

NUCLEAR SERVICES & TECHNOLOGY

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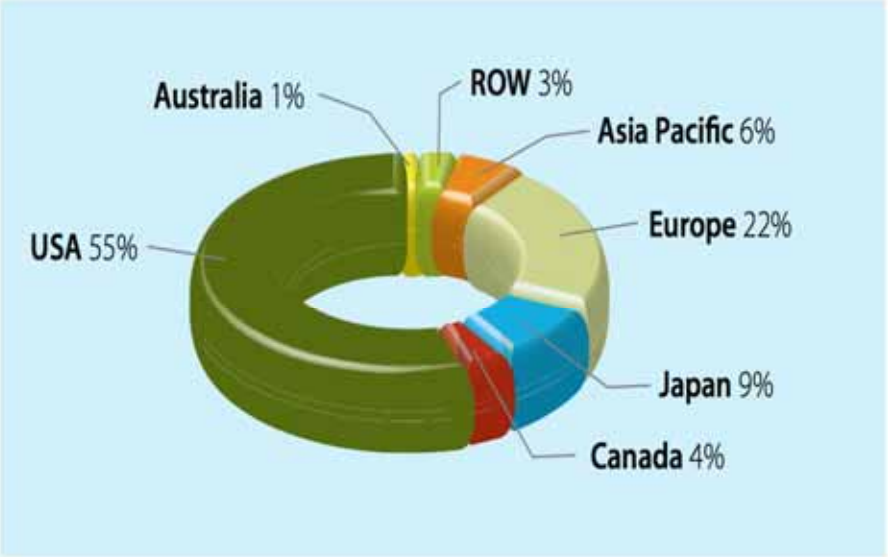
What Is Molybdenum-99 ?

- Mo-99 is the parent isotope of Tc-99m
- Tc-99m is used in over 80% of nuclear medical procedures
- Tc-99m is used globally in over 30 million procedures every year
- Weekly production is only about 0.11g



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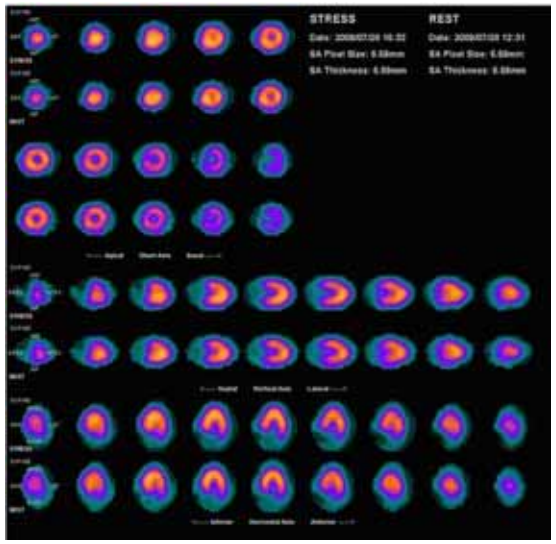
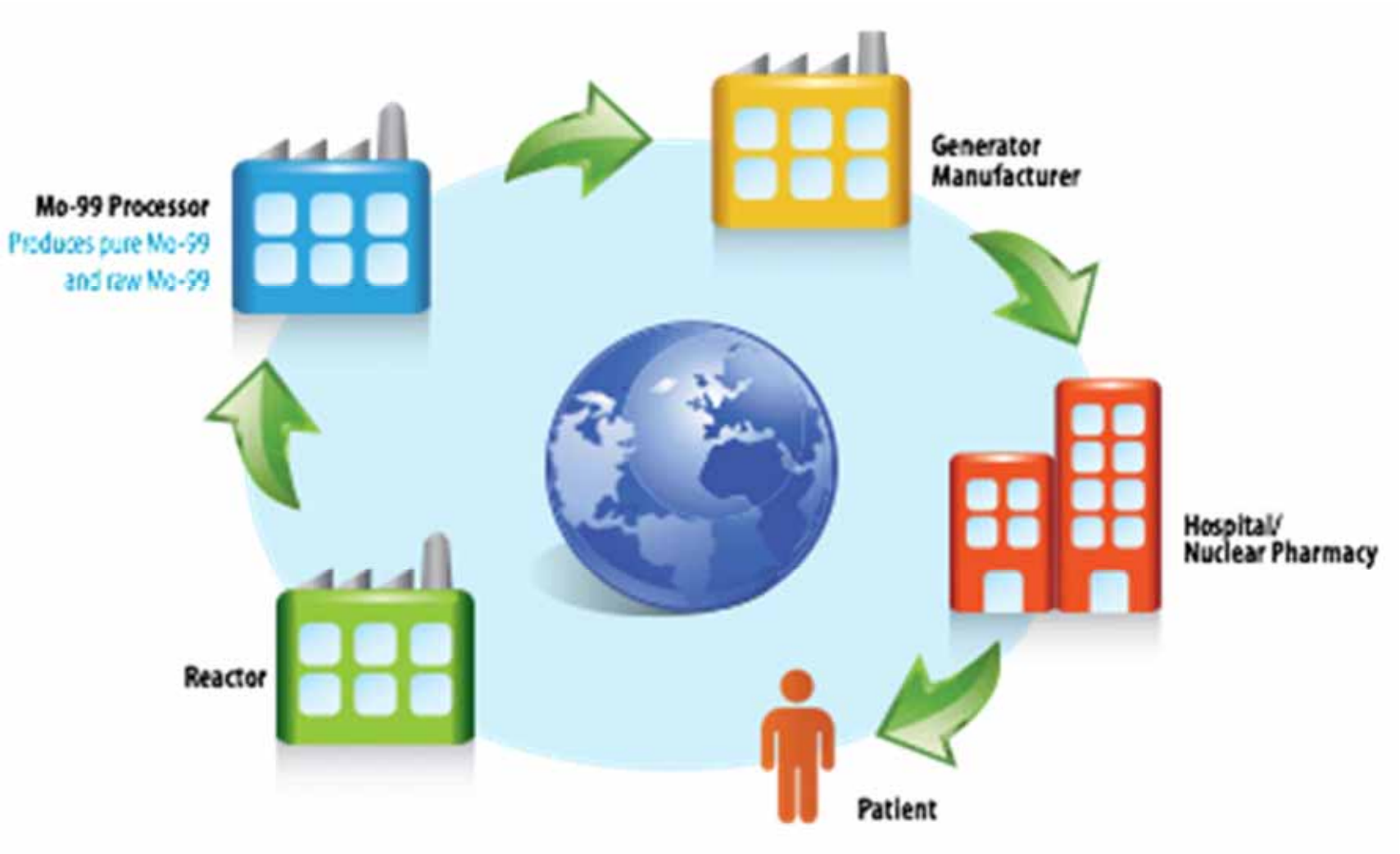
Why Tc-99m ?



- It has a half-life of six hours, so it decays relatively quickly.
- Technetium-99m decays emits gamma rays and low energy electrons, so the radiation dose to the patient is low.
- The low energy gamma rays are accurately detected by a gamma camera.
- Technetium can be incorporated into a wide range of biologically active substances allowing concentration in the particular tissue or organ of interest.

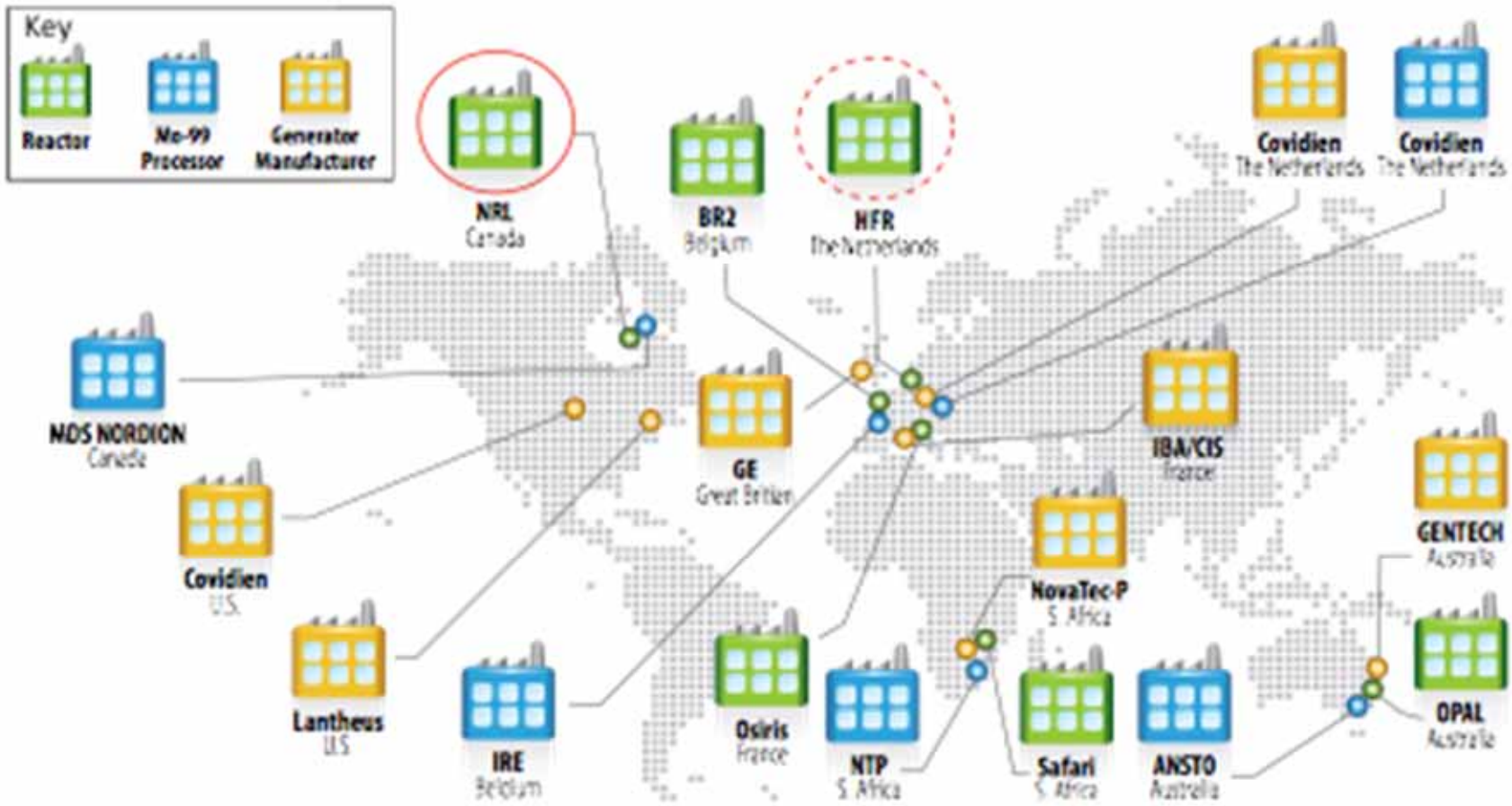
Supply Chain



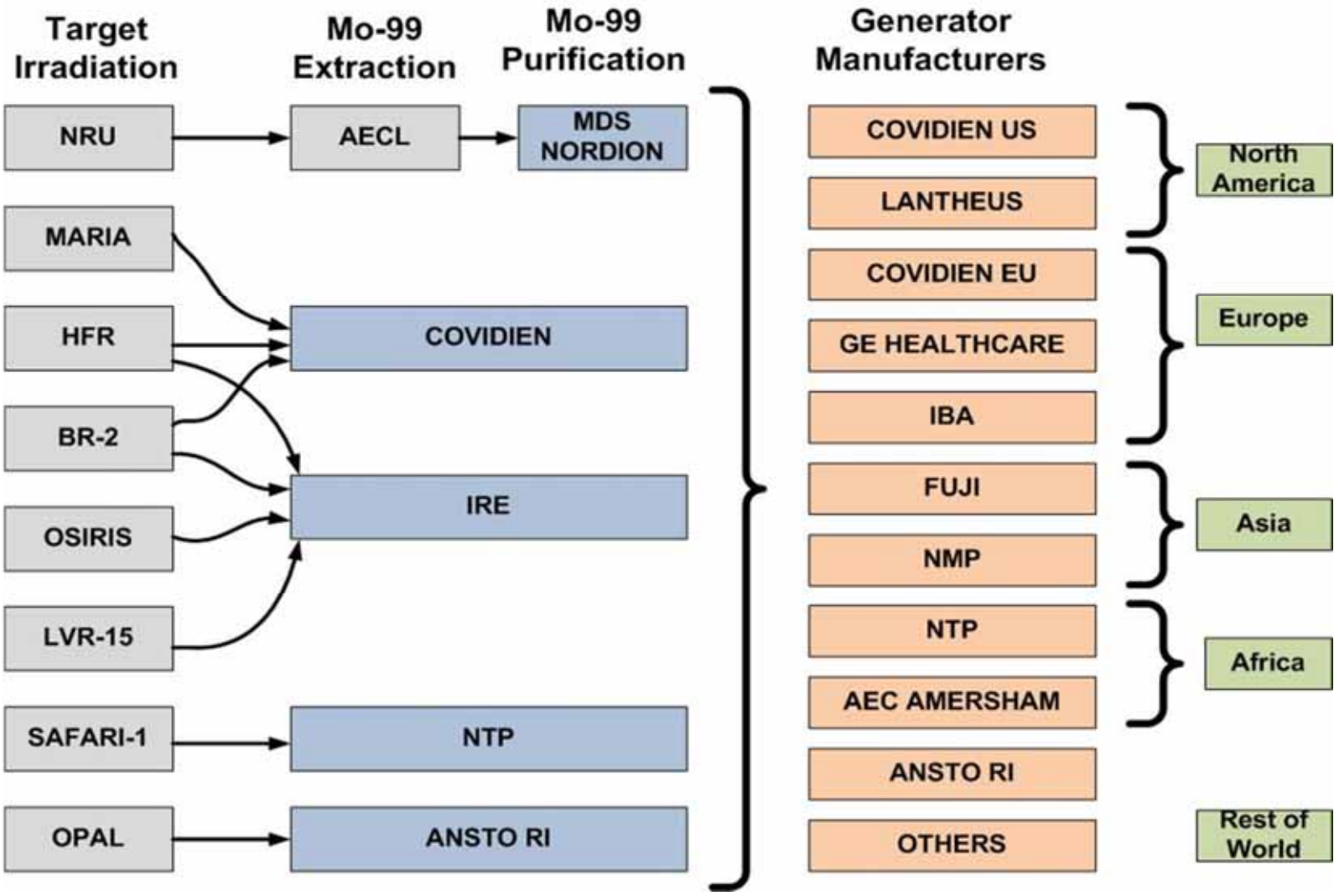
Global Production

Geographic Area	6 Day Curie End Of Production (EOP)
Europe	10,060
Canada	4680
Rest Of World	~3000 (domestic only)
Australia	1000
Japan	0
Asia Pacific	0
USA	0

Global Supply Facilities



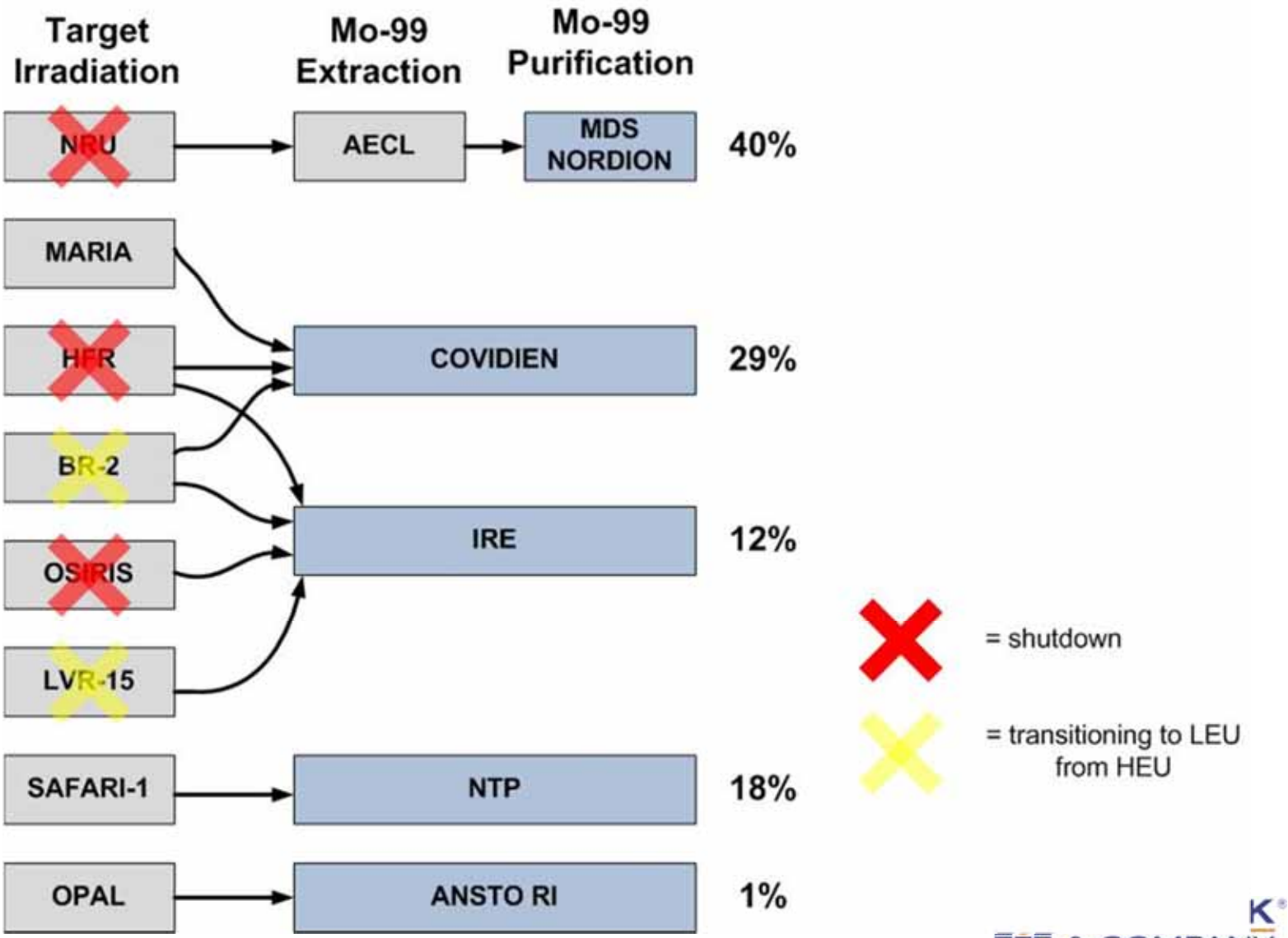
Global Players



The Crisis

- Only six reactors globally produce the world's entire supply of Mo-99
- The High Flux Reactor (HFR) in the Netherlands and the National Research Universal (NRU) reactor supply 65% of the worlds Mo-99 and are closing down in 2016-2018
- With the exception of Australia's Opal reactor, all were originally built to use HEU fuel
- Safari-1 has been converted to use LEU

Yup, It's Really A Crisis



Something MUST Be Done !

Globally:

- ANSTO Opal reactor: Has potential irradiation capacity to meet world demand. Seeking to boost their production to 4000 Ci/week. Project awaits funding approval expected in late October 2012.
- SAFARI-1 Transitioned to using LEU targets with acceptable yield.
- Belgium BR-2 reactor: Installation of additional (50% increase) irradiation capacity.
- Canada: Investigating, with some success, Tc-99m using energetic proton bombardment of highly enriched Mo-100 in a cyclotron.

Something MUST Be Done….Still !

Domestically

- NNSA (National Nuclear Security Administration, DoE) has entered into cooperative agreements with four US entities to support the development of a domestic Mo-99 supply
  - Morgridge Institute for Research to develop accelerator technology with LEU fission
  - B&W Technical Services Group to develop LEU Aqueous Homogenous Reactor technology
  - GE Hitachi Nuclear Energy to develop neutron capture technology
  - NorthStar Medical Radioisotopes to develop accelerator technology

Commercial Challenges

- Mo-99 production is NOT a level playing field
  - Market pricing has been artificially low due to subsidies (both direct and indirect).
  - Extreme Barriers to entry for decades.
  - Processors had extreme market power.
  - Market is restructuring with the significant loss of a part of the supply chain.
  - There is a race to be “first to market” with a new supply chain and/or technology.
  - In other countries, governments have a social contract with the people.
  - In US, Tc-99 procedures were historically cheap, so insurance companies set their reimbursement rates low.
  - Insurance companies want to keep their expenses low.

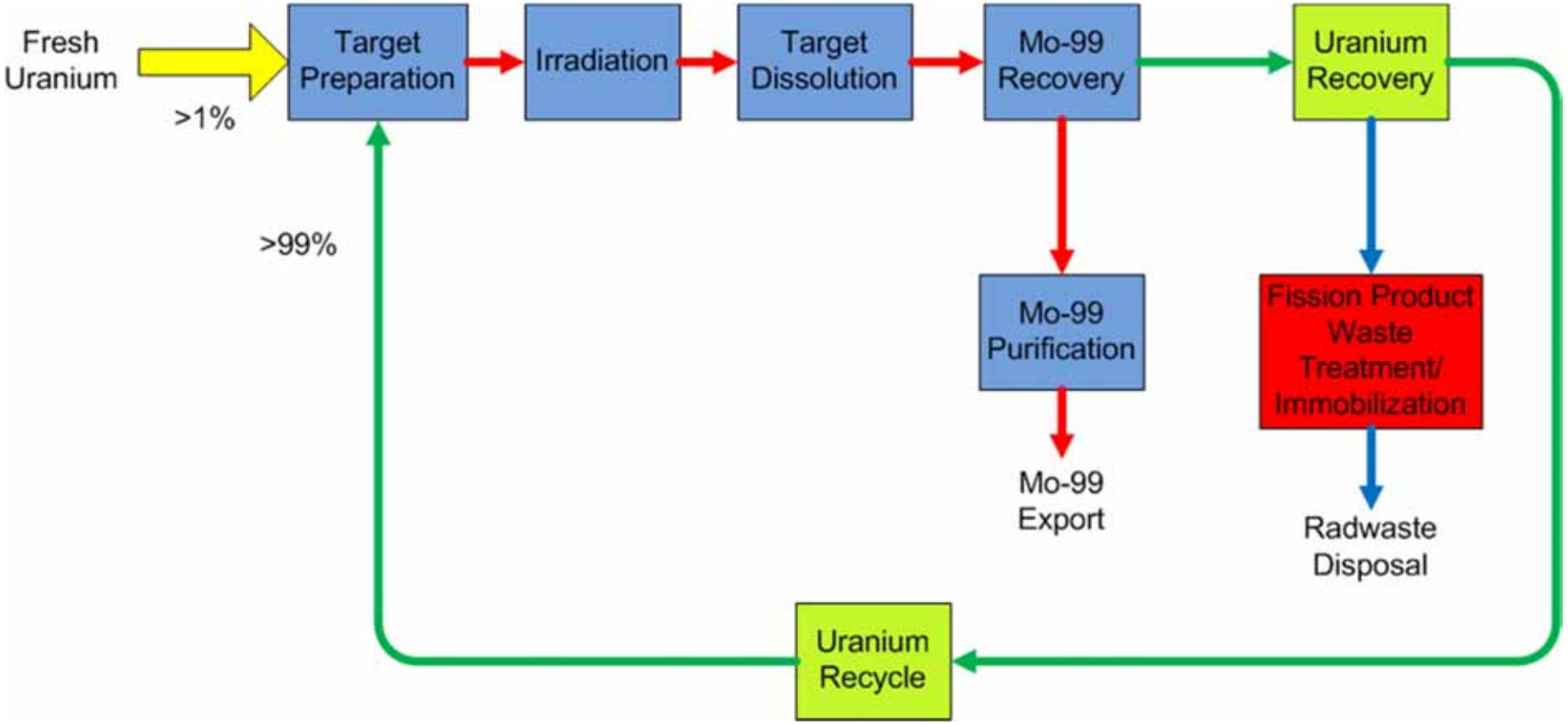
Historical Pricing Distortions

- All of the reactors in use today for Mo-99 were originally constructed and operated with 100% government funding.
- Reactor capital costs or depreciation are not factored into the pricing of the Mo-99 product.
- General reactor maintenance and periodic capital updates are not factored into the final pricing of Mo-99.
- When this Mo-99 production started, the separation and purification processing were performed in government operated facilities.

Future Pricing Distortions

- Mo-99 is part of a global supply chain. It will almost certainly be sourced from several countries.
  - Subsidies to support the development and capital costs will vary between countries. Countries have differing drivers for subsidizing
    - Social contract
    - Desire to develop nuclear expertise
    - Security of supply
  - Regulatory and permitting requirements vary widely between nations.
    - NRC, DOE, FDA, EPA, individual States will be players in US. None of these have worked with a Mo-99 producer before.
  - Radioactive waste disposal technical requirements and disposal costs differ widely between countries.

Mo-99 Production BFD



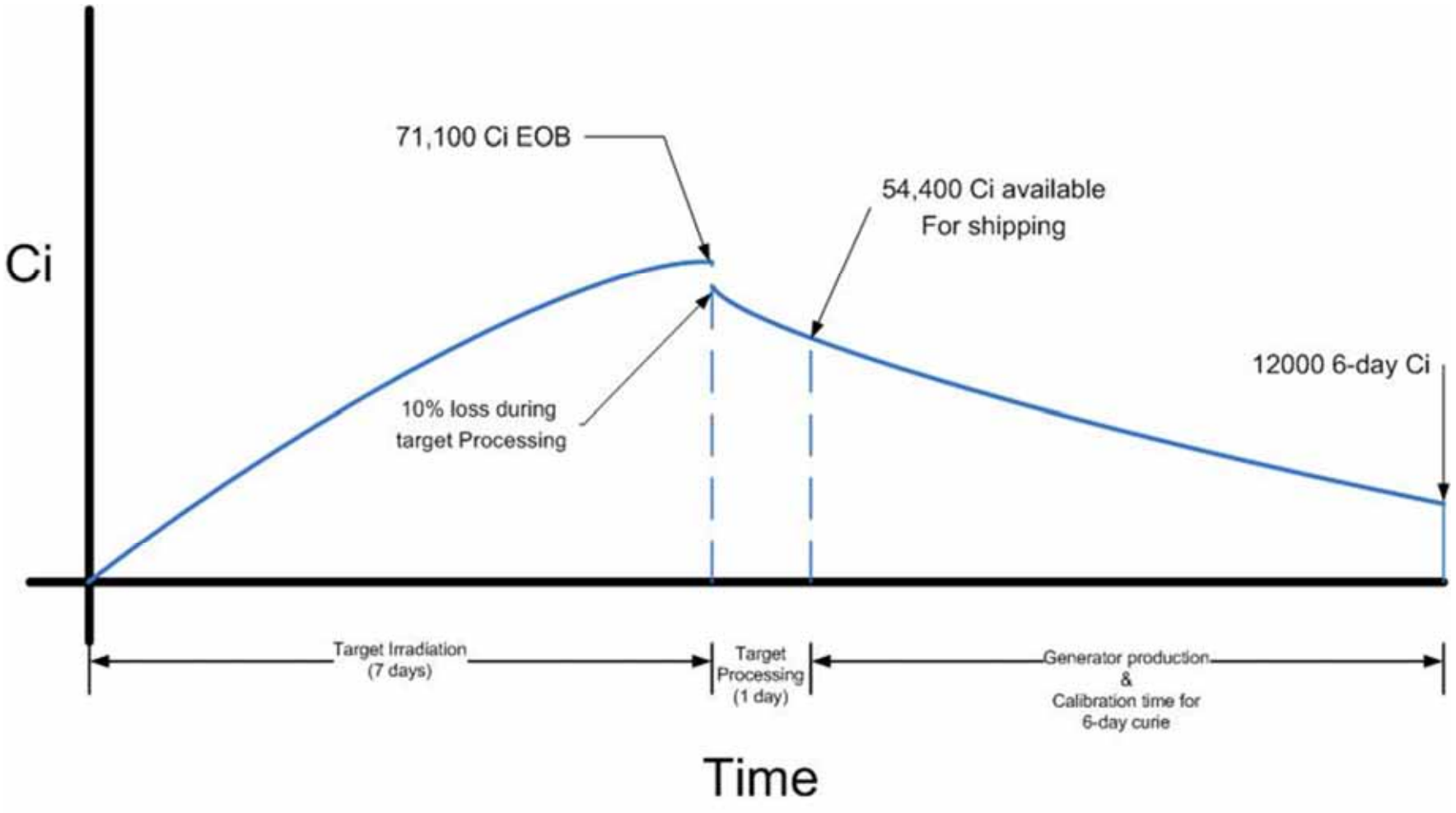
Alternative Irradiation Options

- Proton bombardment of Mo-100
- Bombardment of Mo-100 in a cyclotron
- Neutron activation of Mo-98
- Linear accelerator powered fission

Technical Issues

- Short processing times (lose c. 1% of Mo-99 product per hour)
- Very low concentrations (parts per trillion)
- Very high product purity requirements
  - Iodine is particular contaminant of concern
- Lack of native nuclear engineering expertise
- Switch from HEU to LEU
  - Driven by nuclear non-proliferation concerns
  - Generates more radioactive waste
- Noble gas removal

Processing Timeline



Noble Gas Removal

- Krypton and Xenon generated by fission of U-235
  - Mo-99 production is optimized using low U-235 burn-up and short cooling
  - Uh-oh ! That's the same irradiation characteristics as Plutonium production for nuclear weapons
  - Radioactive Xe monitoring is the primary means of detection of weapons testing and processing operations for weapons manufacture
  - Xe releases from Mo-99 production can raise questions and mask covert weapons programs
  - Xe capture and decay will almost certainly be a requirement of future Mo-99 production

Summary

- Mo-99 has become indispensable to modern diagnostic medicine
- The current pricing structure is unsustainable in the global marketplace
- The world supply chain will shortly undergo dramatic disruptions
- The race to replace the lost capacity is very challenging technically and politically
- Chemical engineers will be at the heart of solving this problem

Q & A

Thankyou For Listening