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Innovative Approaches to the Management of Irradiated Nuclear Graphite Wastes: Addressing the Challenges through International Collaboration with Project 'GRAPA'

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In Decommissioning…

“Graphite is a Difficult Material”

(Michele Laraia: this conference, Wednesday morning!)

Unique, yes…

Difficult? Maybe not, if we stop being indecisive!

>250,000 tonnes irradiated graphite world-wide (“*i*-graphite”)

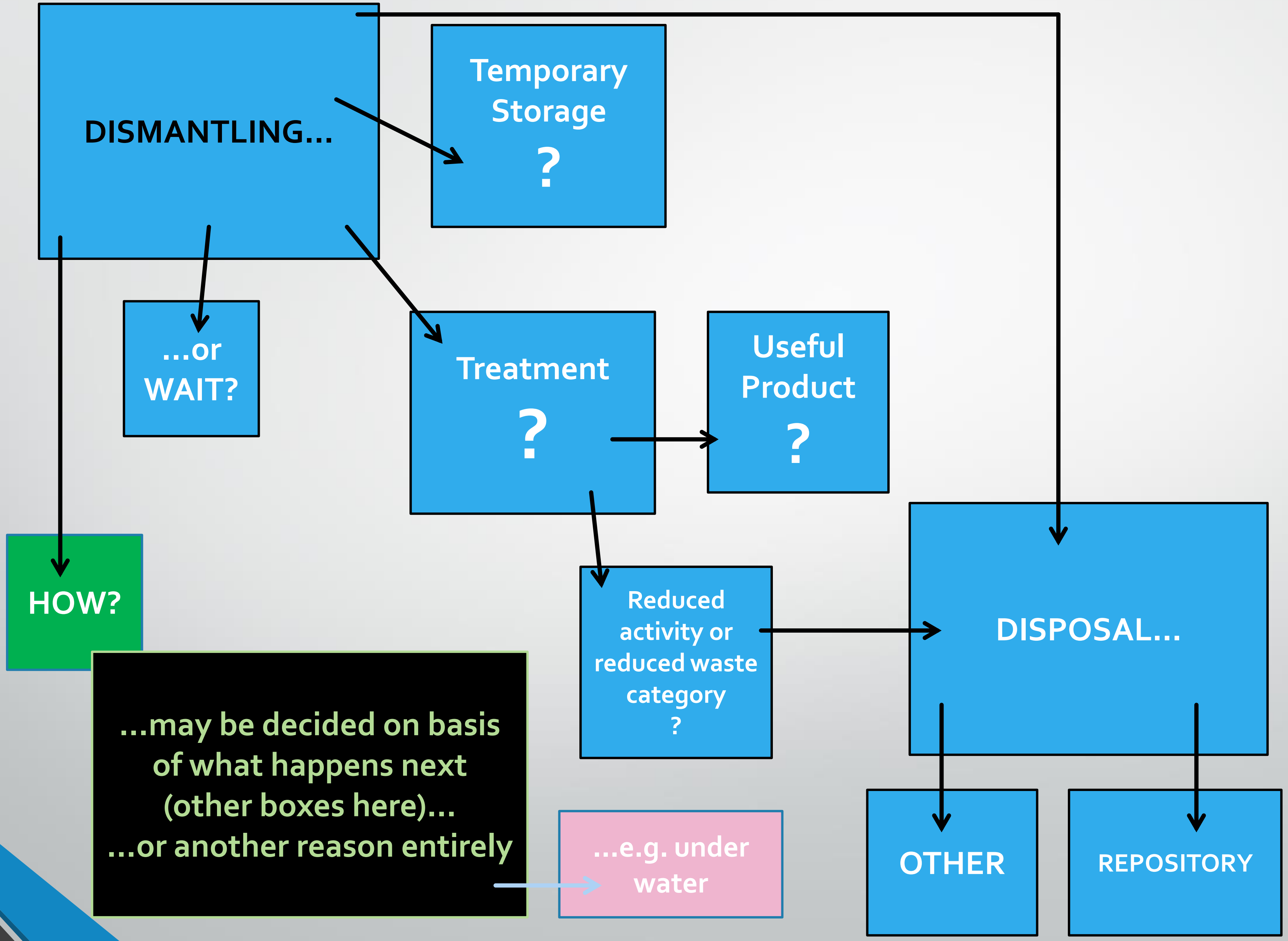
- Mostly from reactor moderators and reflectors
- Some from nuclear fuel elements
- Fast neutrons cause ‘damage’ to the graphitic crystal structures leading components to shrink and distort, to crack, and therefore, long-term, can result in the reactor being closed down because fuel and control rods cannot be guaranteed to move freely;
- Ionising radiation (principally *gamma*) results in oxidation if the graphite is in air or (most often) carbon dioxide;
- Slow neutrons create new radioactive isotopes both from the graphite (*i.e.* ^{14}C, ^{36}Cl) and from impurities;
- Graphite stacks may also contain metallic components (wires, pins etc.)

- The UK has >80,000 tonnes or irradiated graphite wastes; world-wide there are 250,000 tonnes. France (~30,000 tonnes) and Ignalina NPP in Lithuania, (~3,400 tonnes) need a quick solution…
- Member States entering the HTR 'arena' must have a plan for their i-graphite and carbonaceous wastes
- There are no suitable disposal facilities yet.
- What to do?

Current Options may appear to be:

- 'Safe Storage' in reactor vessels or containments
- Treatment of fuel pebbles/particles and/or graphite
- Progress with deep repository construction
- Case for shallow repository disposal
- Do nothing!

… … … but we should also think laterally!

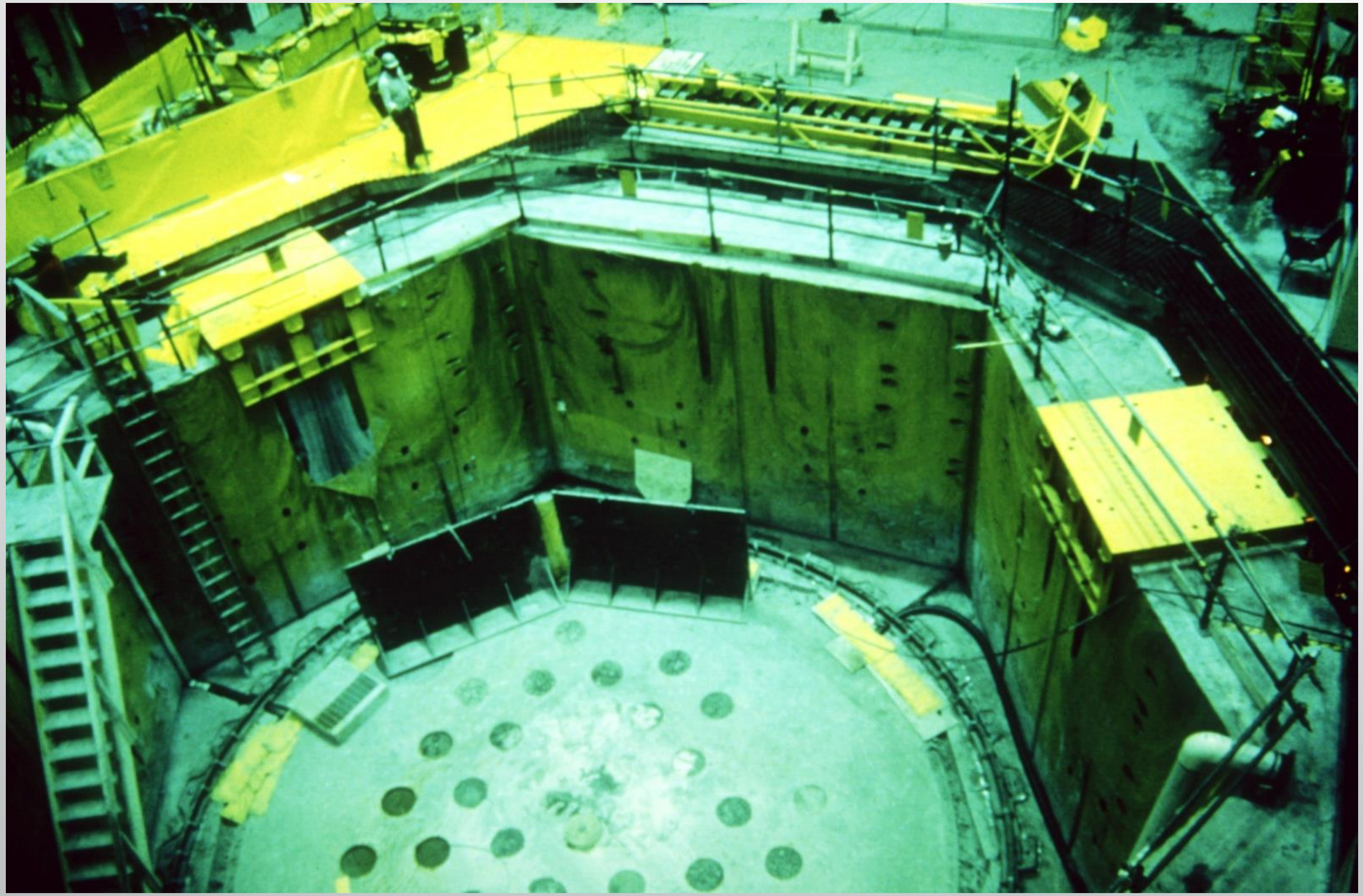


DISMANTLING…
Temporary Storage ?
…or WAIT?
Treatment ?
Useful Product ?
HOW?
Reduced activity or reduced waste category ?
DISPOSAL…
…may be decided on basis of what happens next (other boxes here)…
…or another reason entirely
…e.g. under water
OTHER
REPOSITORY

- Remove graphite from the reactor containment (methodology might depend upon what happens after);
- ?? Package and store ??
- ?? Treat either to give useful product or to reduce radioactivity ??
- ?? Dispose in "temporary" sub-surface facility ??
- ?? Chemical / physical treatment, perhaps to reduce volume or to "consume" completely ??
- Irretrievable disposal in suitable deep repository (or in suitable cases, a shallow repository)

Successful Core Dismantling

- Fort St. Vrain, USA



Unfortunately, the graphite and fuel blocks remain in 'temporary' storage

Successful Core Dismantling

- WAGR, UK

"If your decommissioning plan involves building a new building, then it is the wrong plan"

Successful Core Dismantling

- GLEEP, UK

Successful Core Dismantling

- FORT St. VRAIN, USA – UNDERWATER (for shielding reasons unrelated to the graphite itself)
- WAGR, UK – In air: remote handling, questions of dust explosibility satisfactority resolved
- GLEEP, UK – In air, and by hand (very low irradiation), also allowing ^{14}C to be removed by calcination in an industrial non-nuclear facility, taking advantage of the unexpected mobility of this isotope

AND, FINALLY:

- BROOKHAVEN, USA – In air with viscous sprays, remote handling… THE 'BRUTALIST' METHOD!

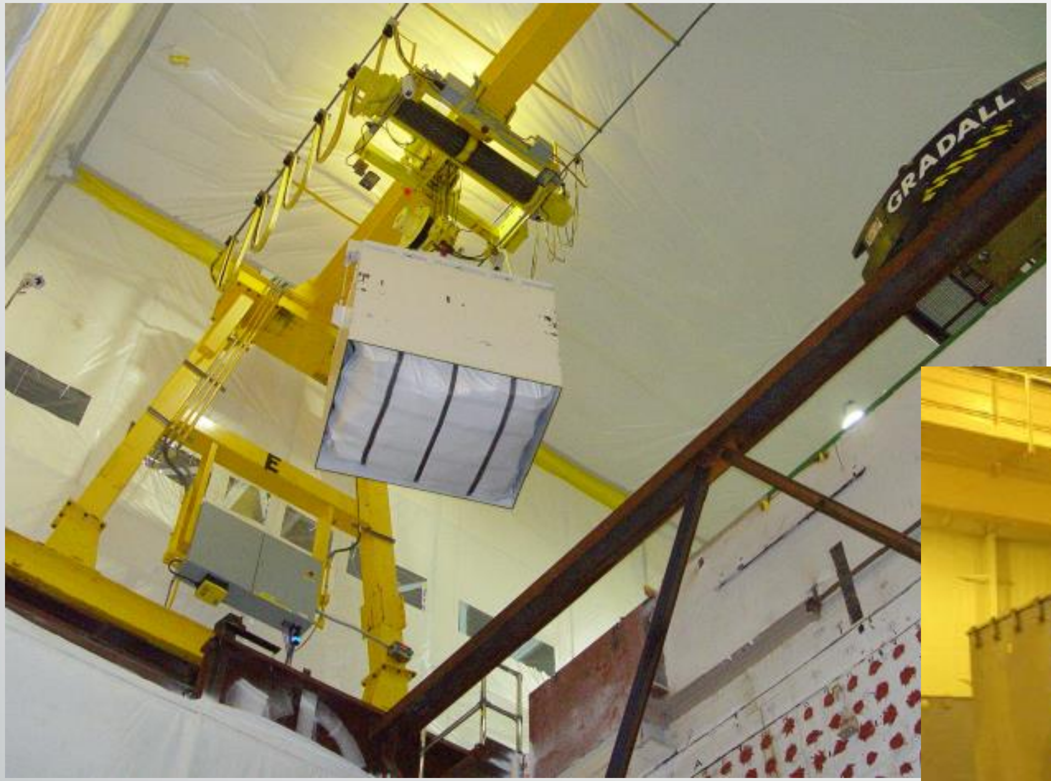
Graphite Removal - BGRR (1)

Note use of 'Fixative' for Dust and Contamination Control

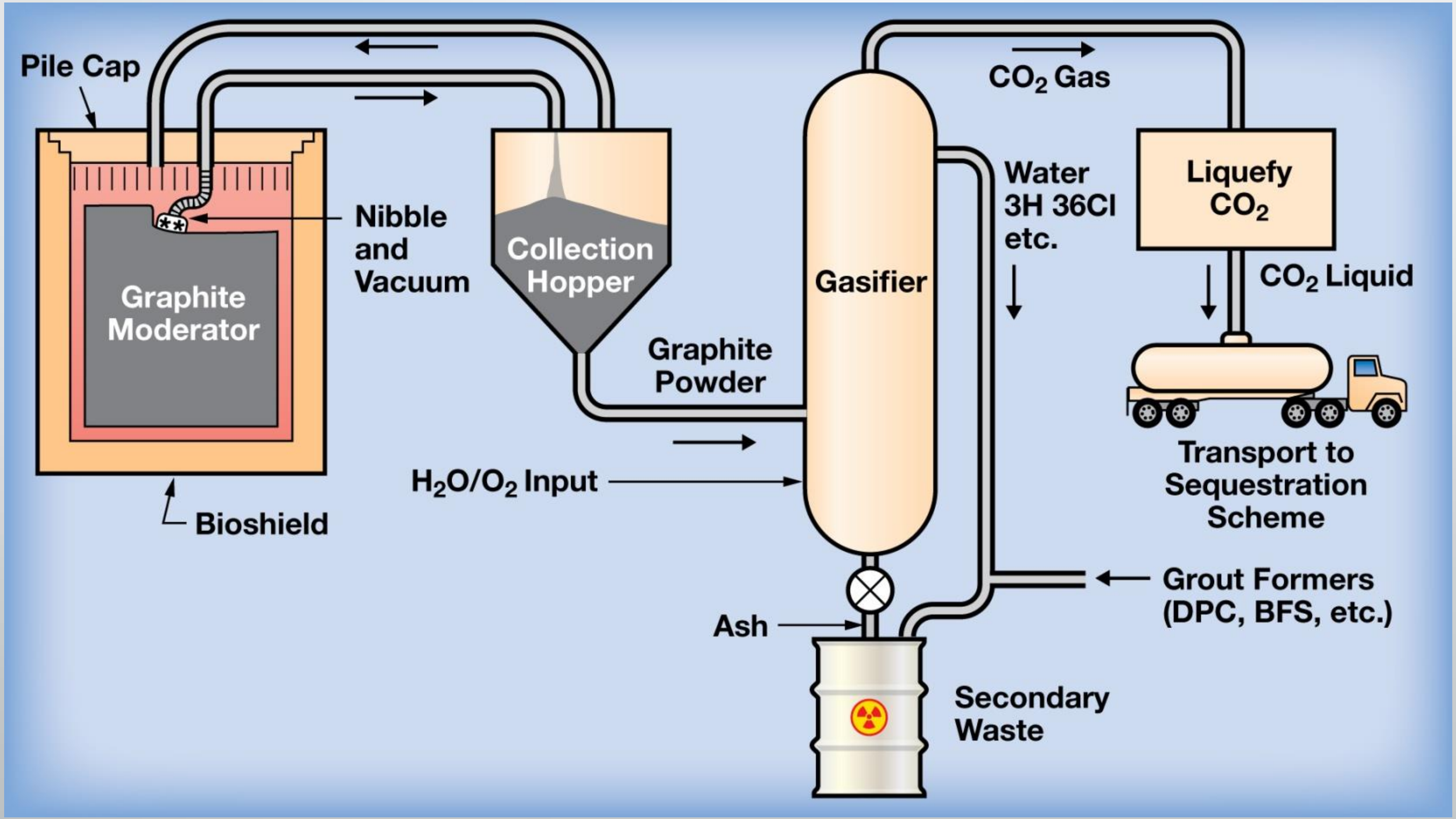
Note also that this graphite contains significant Wigner energy
and that no problems were encountered…

Graphite Removal - BGRR (2)

Graphite Removal - BGRR (3)



Lateral Thinking: An Example of an ‘Integrated’ (and Eco-friendly) Scheme – “Nibble and Vacuum” with Sequestration of $^{14}CO_2$



The Role of IAEA in *i*-Graphite Management

- The IAEA does NOT prescribe policy on radwaste management.
- The objective is to advise Member States of the various options which are being researched, to enable them to make an informed decision on the correct policy for their situation

- 1984: Keynote EU analysis
- 1995: IAEA Technical Meeting "Graphite Moderator Lifecycle Technologies", Bath UK
- 1999: IAEA Technical Meeting "Nuclear Graphite Waste Management", Manchester, UK
- 2006 – 2012: EPRI "Graphite Decommissioning Initiative": six comprehensive reviews on all aspects of *i*-graphite disposal
- 2007: IAEA Technical Meeting "Progress in Radioactive Waste Management", Manchester, UK
- 2008 -2013: EU CARBOWASTE project
- 2011 - 2014: IAEA Collaborative Research Programme "Treatment of Irradiated Graphite to meet Acceptance Criteria for Waste Disposal"
- 2013 – 2016: EU CAST project ('Carbon-14 Source Term')

The Current Position is Summarised in the Recent IAEA TECDOC:

"Processing of Irradiated Graphite to Meet Acceptance Criteria for Waste Disposal: Results of a Coordinated Research Project"

IAEA TECDOC-1790, 135 pp. and CD-ROM, IAEA, Vienna (2016).

…and that leads us neatly to the latest initiative: 'GRAPA'

*'Irradiated **GRA**phite **P**rocessing **A**pproaches'*

Approach for GRAPA

Combining holistic, detailed and specific views

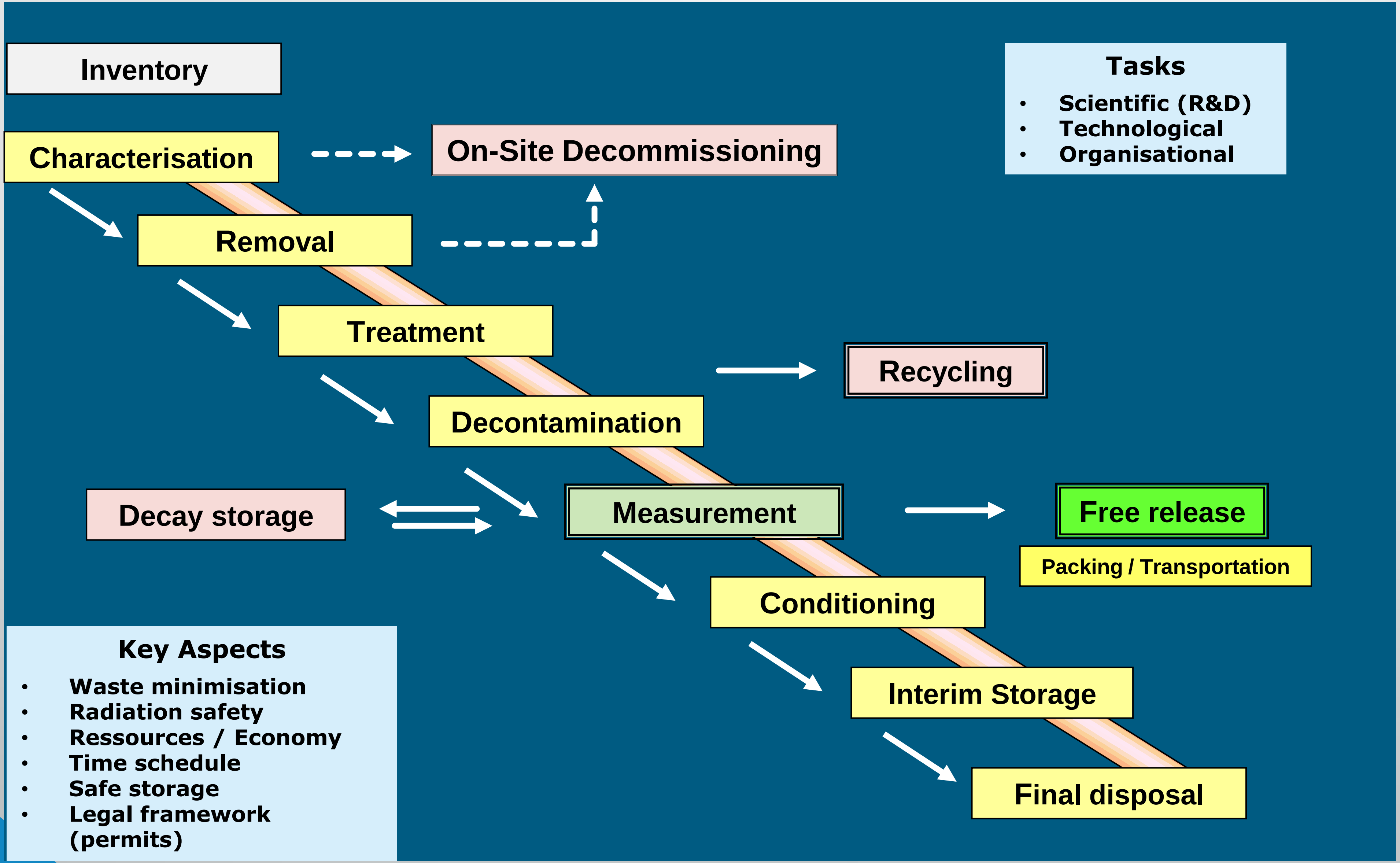
Technical Decommissioning Concept

- **Considering** all information and documents
- **Evaluating** all requirements whether technical, operational, legal, and alternatives
- **Specifying** all resources (budget, machinery, personal etc.)
- **Combining** views of various specialists from different disciplines

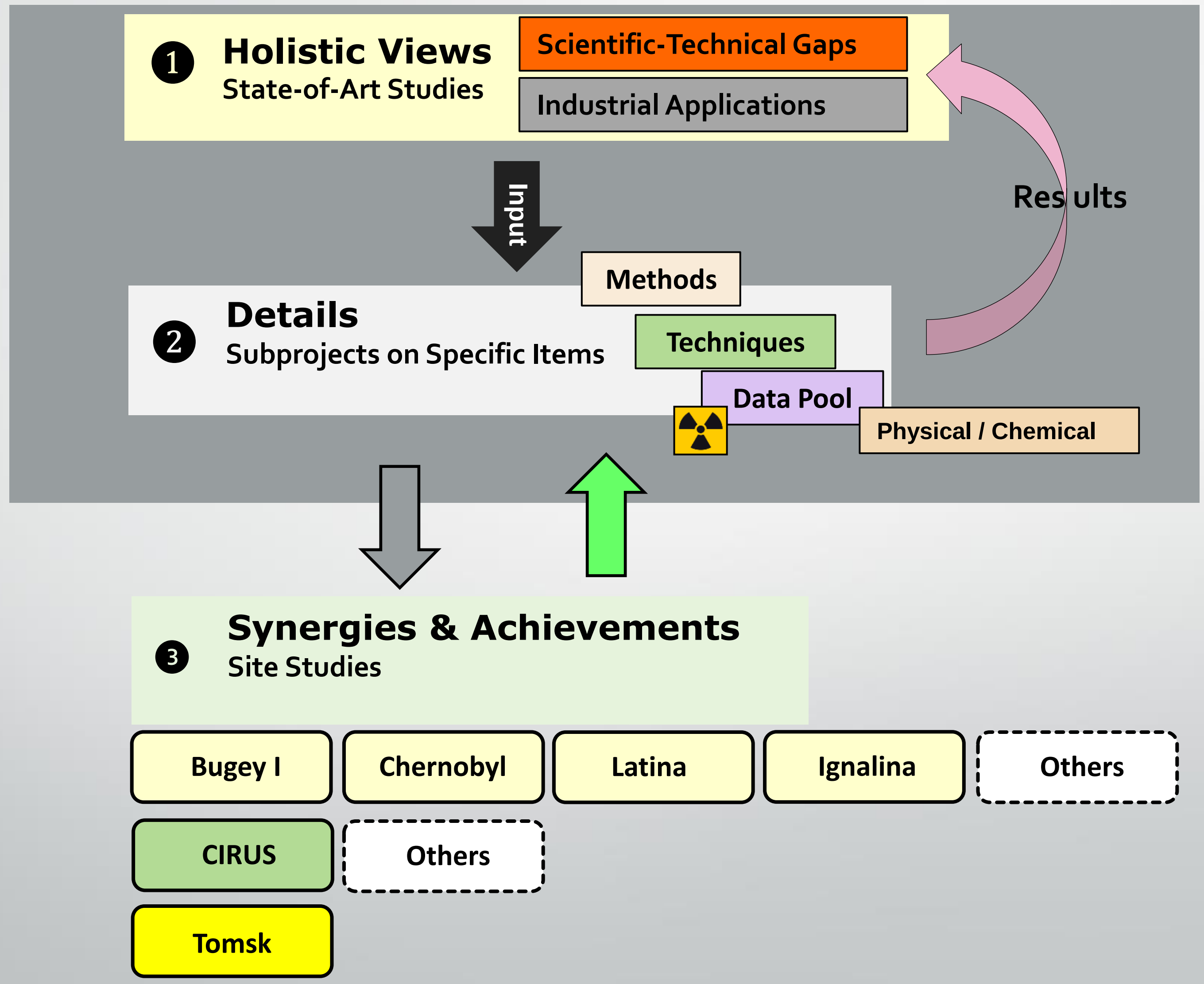
- **Taking the „helicopter perspective" as well as looking on important details**
- **Identifying gaps (and the possibilities to close them)**
- **Discussing open or unresolved questions**

Developing a Modular Disposal Concept where appropriate

Generic Disposal Concept: Target-Oriented Process Chain



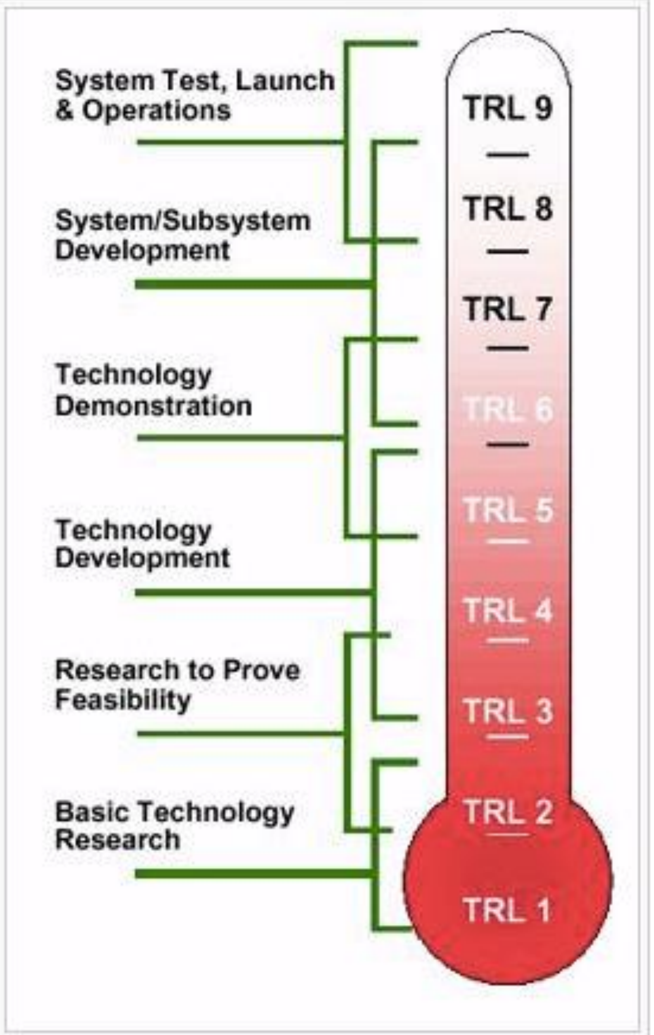
'GRAPA' Structure



Technology Readiness Level – Assessing the Status of Developments

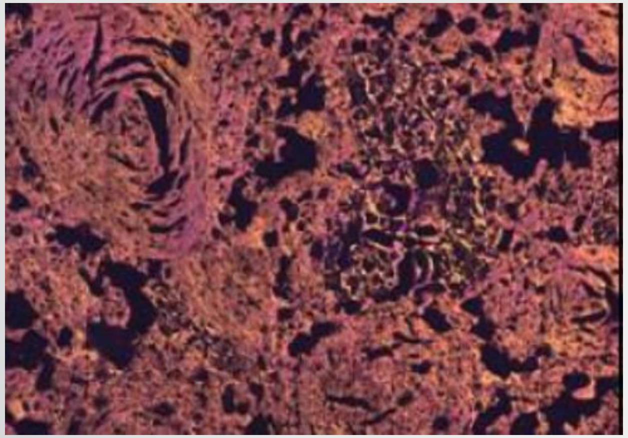
Phase	TRL	Stage	Description
Operations	TRL9	Operations	The technology is being operationally used in an active facility
Deployment	TRL8	Active Commissioning	The technology is undergoing active commissioning
	TRL7	Inactive Commissioning	The technology is undergoing inactive commissioning. This can include works testing and factory trials but it will be on the final designed equipment, which will be tested using inactive simulants comparable to that expected during operations. Testing at or near full throughput will be expected
Development	TRL6	Large Scale	The technology is undergoing testing at or near full-scale size. The design will not have been finalised and the equipment will be in the process of modification. It may use a limited range of simulants and not achieve full throughput
	TRL5	Pilot Scale	The technology is undergoing testing at small to medium scale size in order to demonstrate specific aspects of the design
	TRL4	Bench Scale	The technology is starting to be developed in a laboratory or research facility.
Research	TRL3	Proof of Concept	Demonstration, in principle, that the invention has the potential to work
	TRL2	Invention and Research	A practical application is invented or the investigation of phenomena, acquisition of new knowledge, or correction and integration of previous knowledge
	TRL1	Basic principles	The basic properties have been established

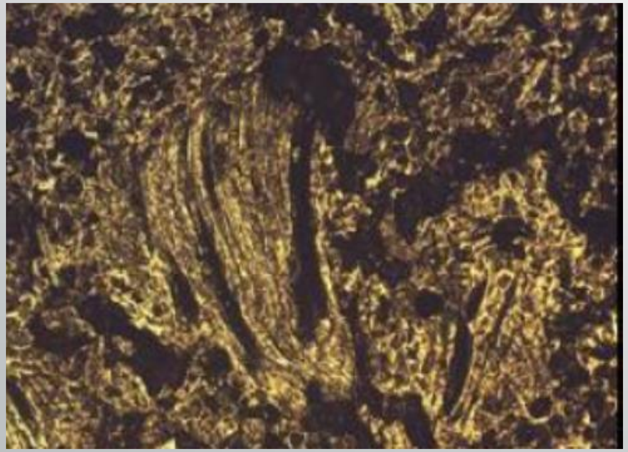
Figure 1: Technology Readiness Level Scale



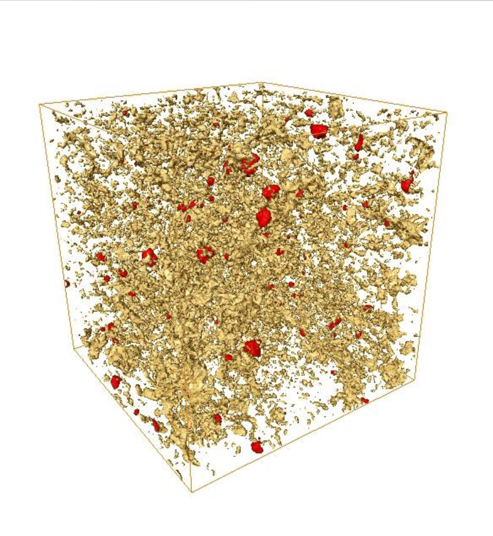
NASA Technology Readiness Levels

GRAPA – 'Characterisation'



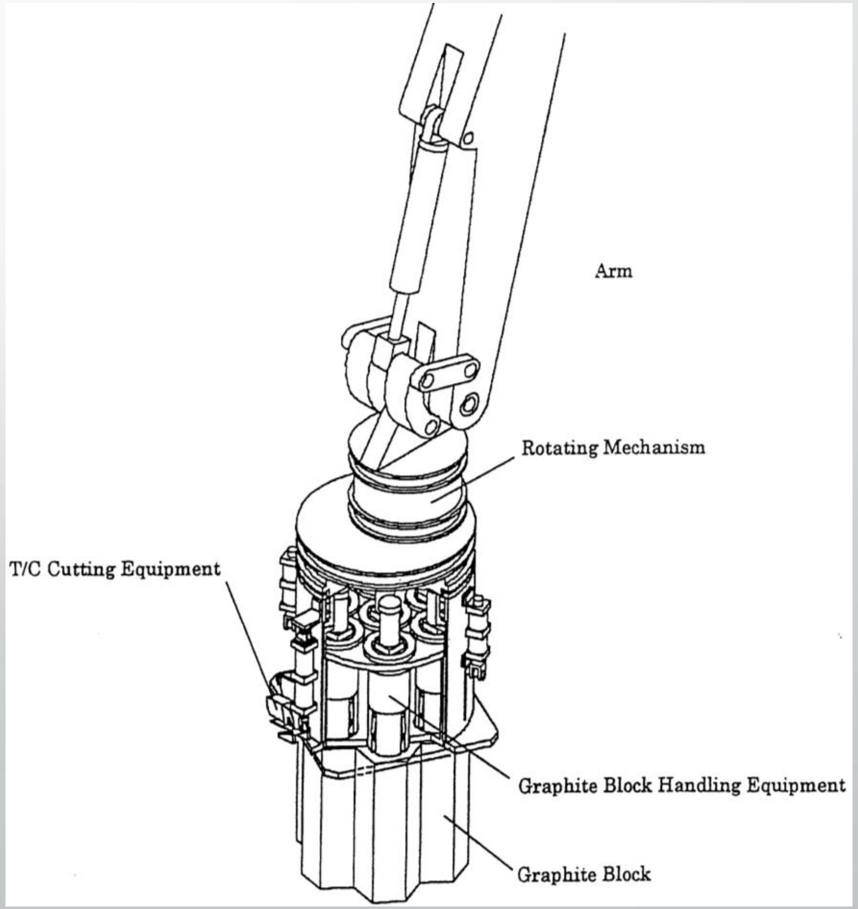


- 1.1 Review 'cross-cutting' documents
- 1.2 Impurity distribution
- 1.3 Models of Reactor Graphite Activation
- 1.4 Radiological Characterisation
- 1.5 Leaching Information
- 1.6 Wigner Energy
- 1.7 Mechanical Characterisation



GRAPA – 'Removal / Retrieval'

- 2.1 Nibble & Vacuum
- 2.2 Whole Block Retrieval

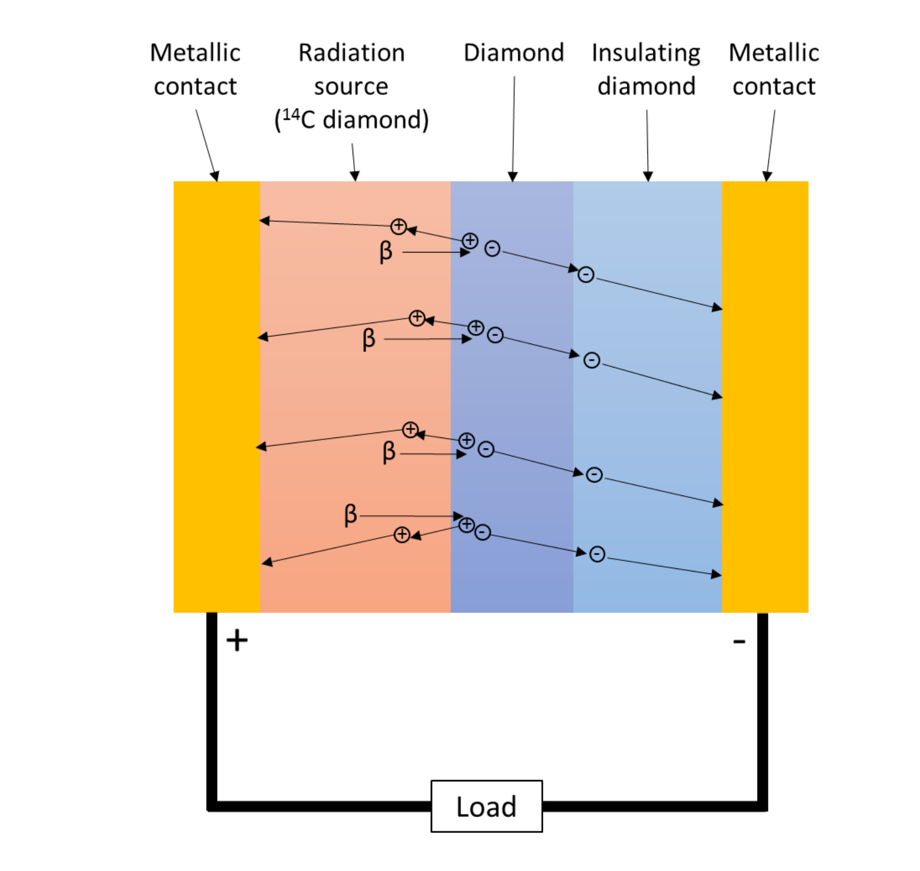


GRAPA – 'Treatment'

- 3.1 Incineration
- 3.2 Plasma Heating
- 3.3 Hot Isostatic Pressing
- 3.4 Microwave Heating
- 3.5 Thermal Decontamination
- 3.6 Chemical (incl Molten Salt)
- 3.7 Supercritical Extraction
- 3.8 Mortar and Concrete

ASPIRE: **A**dvanced **S**elf-**P**owered sensor units in **I**ntense **R**adiation **E**nvironments.

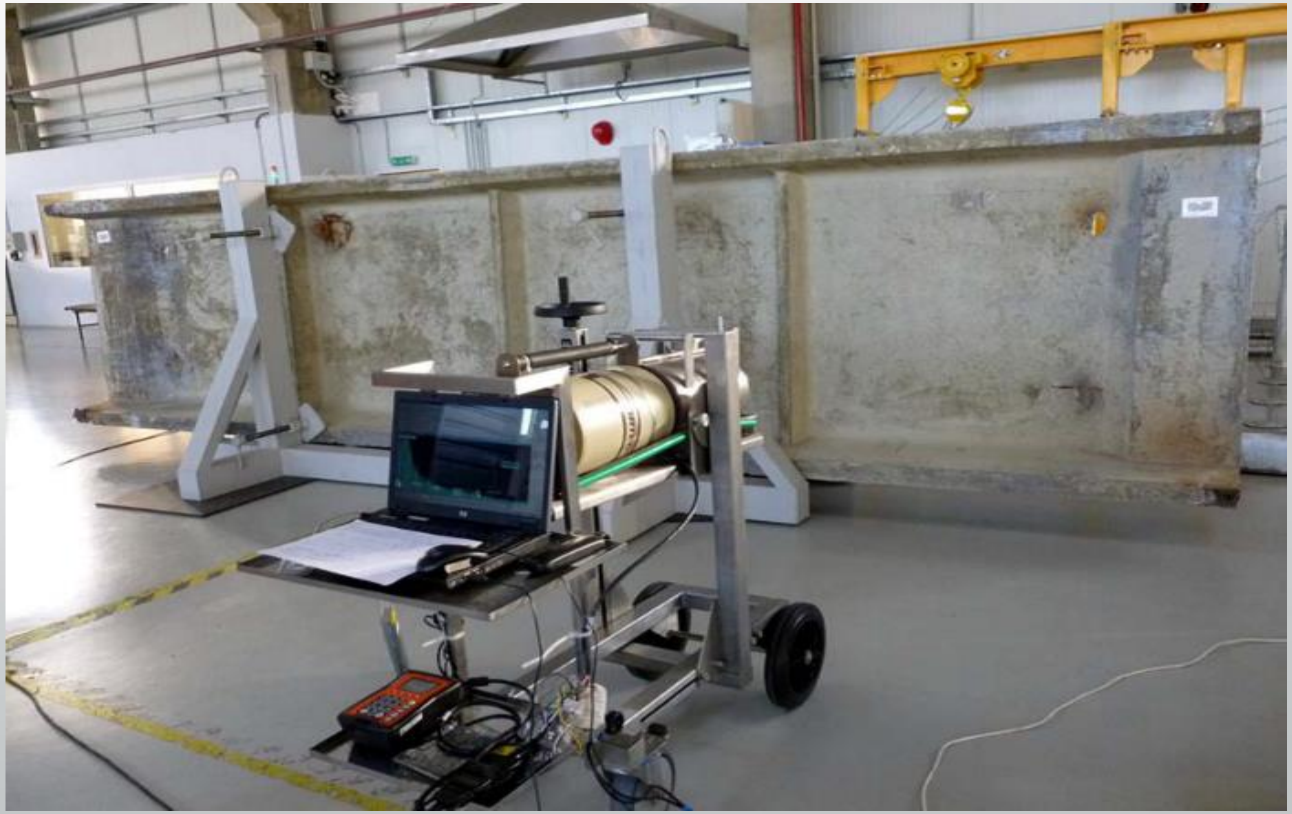
Nuclear battery using ^{14}C waste



- Processing of graphite waste to selectively extract ^{14}C
- Conversion of products into methane for CVD diamond growth
- Enrichment of ^{14}C content using laser separation technologies (in partnership with KAERI)
- Growth of layered CVD diamond with ^{14}C rich diamond encapsulated by non-active ($^{12}C/^{13}C$) diamond
- Spontaneous beta emission generates electron hole pairs, generating a current under load
- Partnered with a capacitor that will be 'trickle charged' by the "nuclear battery" and then discharge at set intervals to power sensory devices (including data transmission) or to continually power low draw devices.
- Very small currents produced, but over very long durations
- *Project start date 01/02/2017 for 36 months (EPSRC funded)*

GRAPA – 'Measurement'

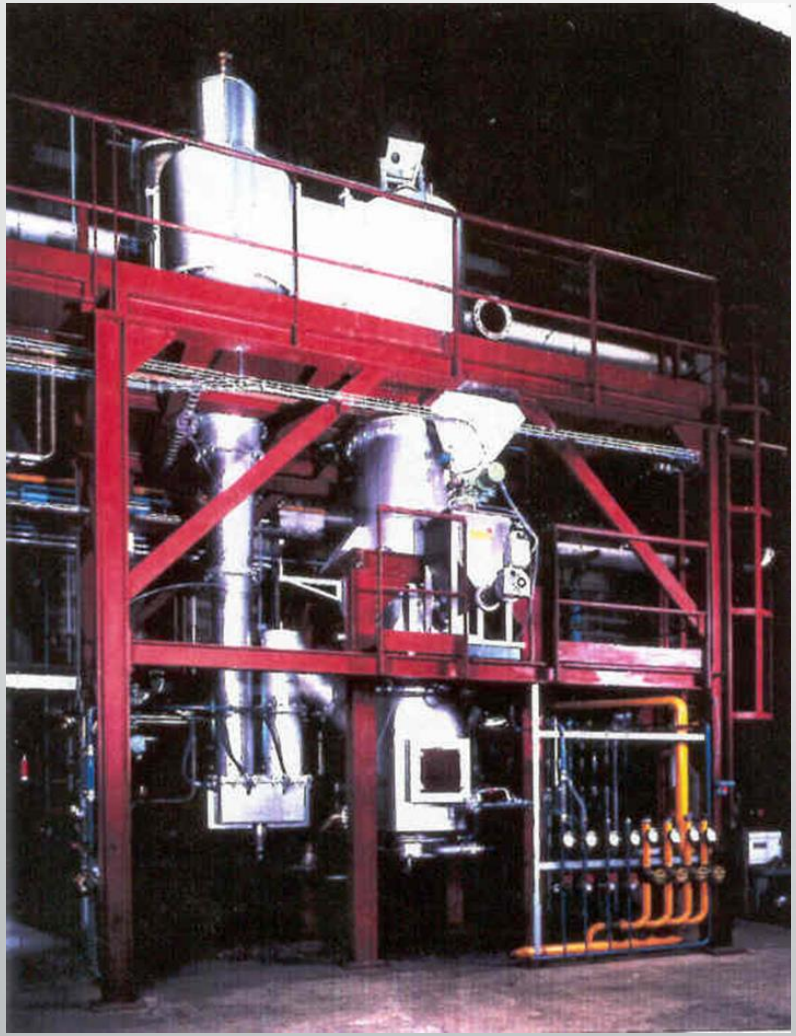
- 4.1 Isotope Ratios in Bulk
- 4.2 Large Scale Classification



GRAPA – 'Packaging, Storage and Disposal'

- 5.1 Packaging
- 5.2 In-Situ Entombment
- 5.3 On-Site Interim Storage
- 5.4 Surface Disposal
- 5.5 Shallow Disposal
- 5.6 Deep Disposal
- 5.7 Potential Exposure Reduction (PER)

GRAPA – 'Towards Industrial Implementation'



PILOT & DEMONSTRATION CENTER FOR DECOMMISSIONING OF URANIUM-GRAPHITE NUCLEAR REACTORS

JSC "PDC UGR" Corporate Objectives:

Provision of commercial decommissioning services for the single-type nuclear facilities based on the standardized technologies suitable for distribution at the nuclear industry enterprises and exporting.

Base for the decommissioning technology development - 2 industrial sites of the Reactor Plant (5 shutdown uranium-graphite reactors).

North site (area 11) – 2 industrial reactor plants

South site (area 2) - 3 industrial reactor plants

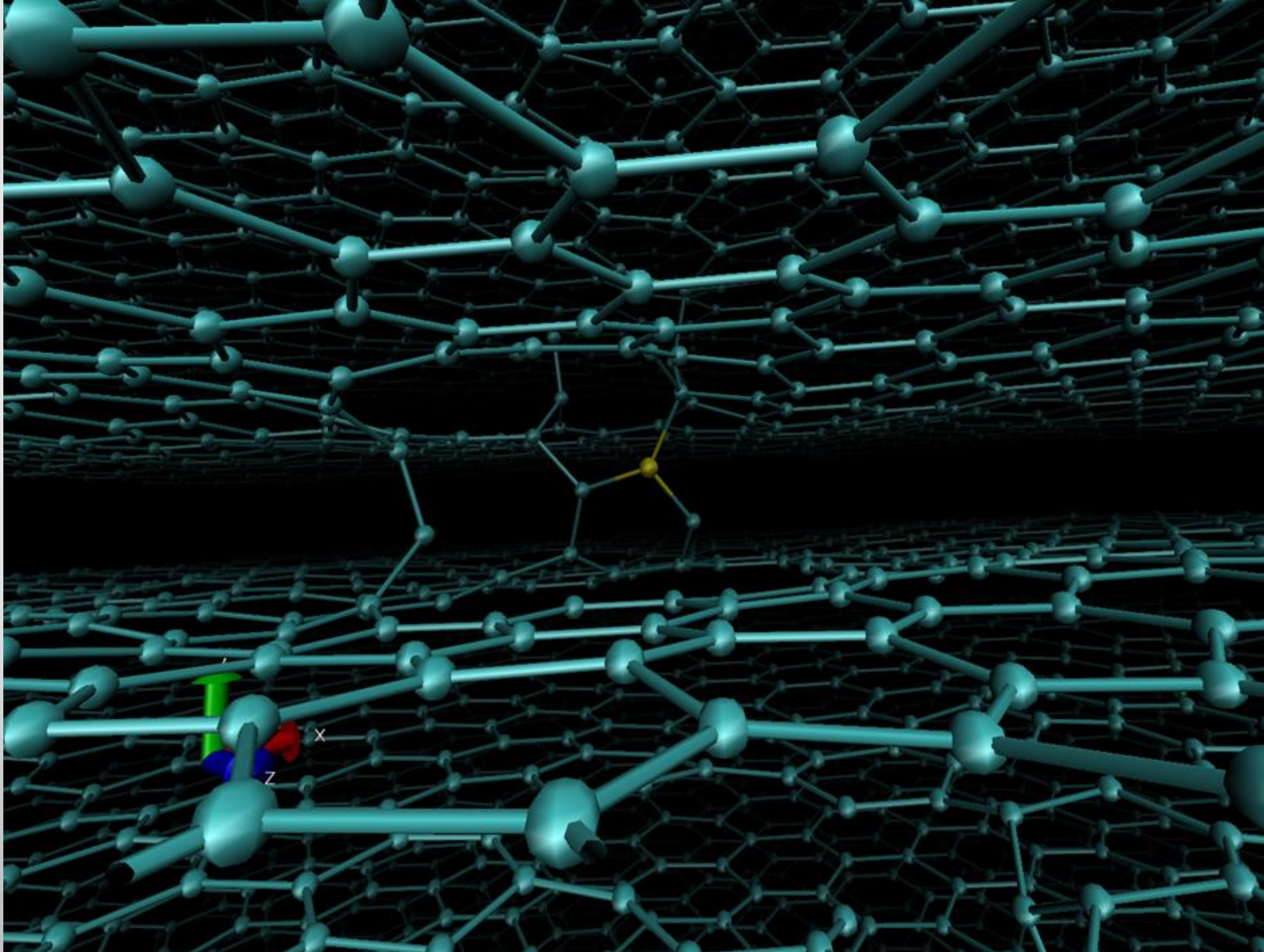
And, lastly...

- Filling ‘gaps’ in the technical and scientific ‘know-how’
- Provisionally identified specific reactor dismantling projects which may ‘inform’ GRAPA synergistically: Ignalina (RBMK); Chernobyl (RBMK special case); Latina (Magnox); Bugey-1 (UNGG); Seversk (Production reactor); CIRUS (India)

- Nominal initial project life is 2 years, but the network will stay in place!
- Partners: EdF/ANDRA/CEA France; FZJ/Technical University Mannheim Germany; IAE/CPST Lithuania; ChNPP Ukraine; SoGIN/Polytechnico Milano Italy; PDC UGR Rosatom Russia; ENRESA/CIEMAT Spain; NDA/RWML/University of Manchester/ Imperial College/University of Bristol UK; PSI Switzerland; KAERI Rep. of Korea; CIRUS India; IFIN-HH Romania

IAEA

International Atomic Energy Agency



Thank you for your attention!