Materials Supply Chains in the UK Power Generation Sector

Nuclear Power (1)

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1 May 2008

Nuclear Power

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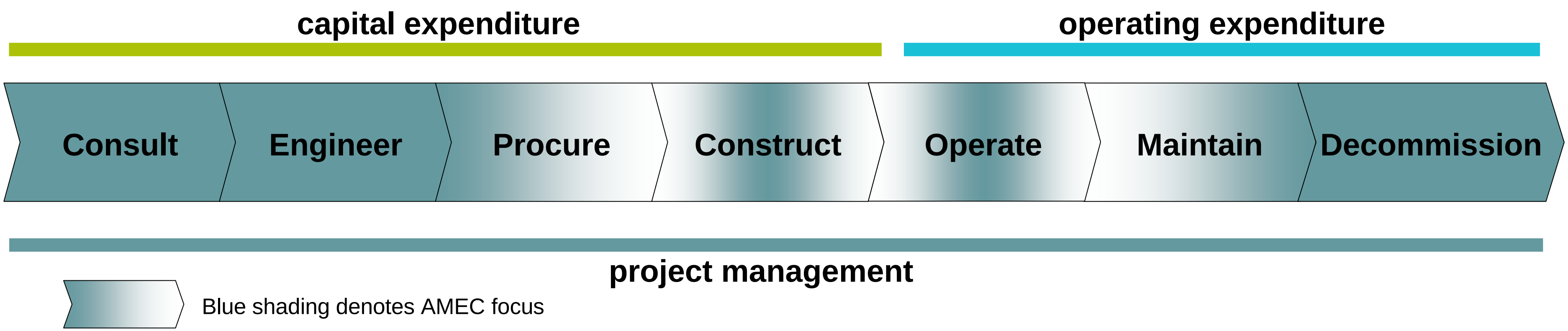
- AMEC at a glance
- New Build
- ITER & Fusion
- Generation IV
- Conclusions

AMEC at a glance

amec

Services focus on designing, managing the delivery of, and maintaining strategic and complex assets

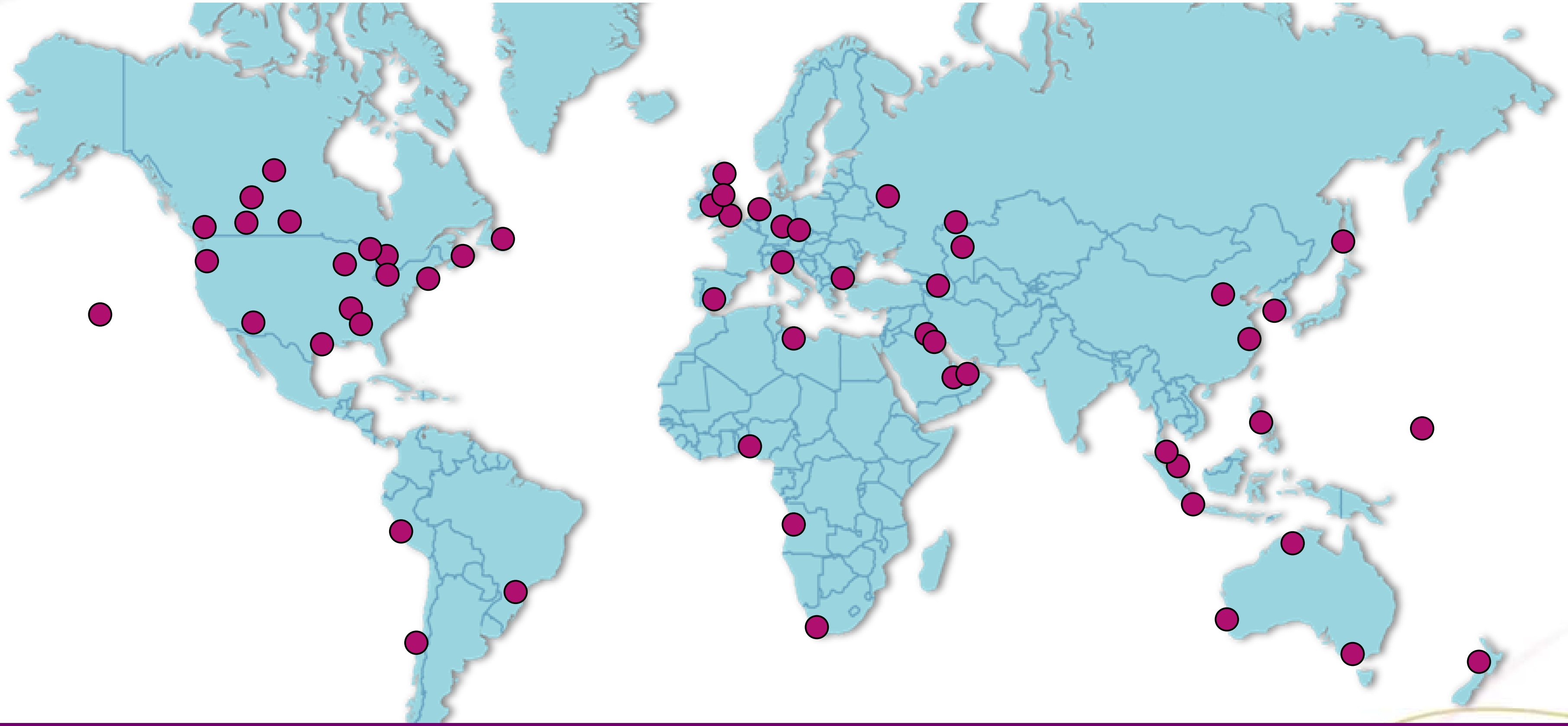


Our vision is to be a leading supplier of high-value consultancy, engineering and project management services to the world's energy, power and process industries

Aspiring to Excellence

Where we are

Main office locations

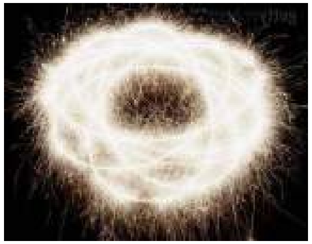


Our 20,000 employees operate from more than 30 countries

Our businesses

Natural Resources

- **Oil and gas services** – design, delivery and commissioning of major upstream oil and gas facilities, commissioning of platforms, project management and operations support and maintenance
- **Oil Sands** – market leader in engineering services and provision of infrastructure to upstream surface mining oil sands sector
- **Minerals and metals mining** – consultancy, design and project management services to clients producing commodities including gold, diamonds, base metals, potash and uranium.



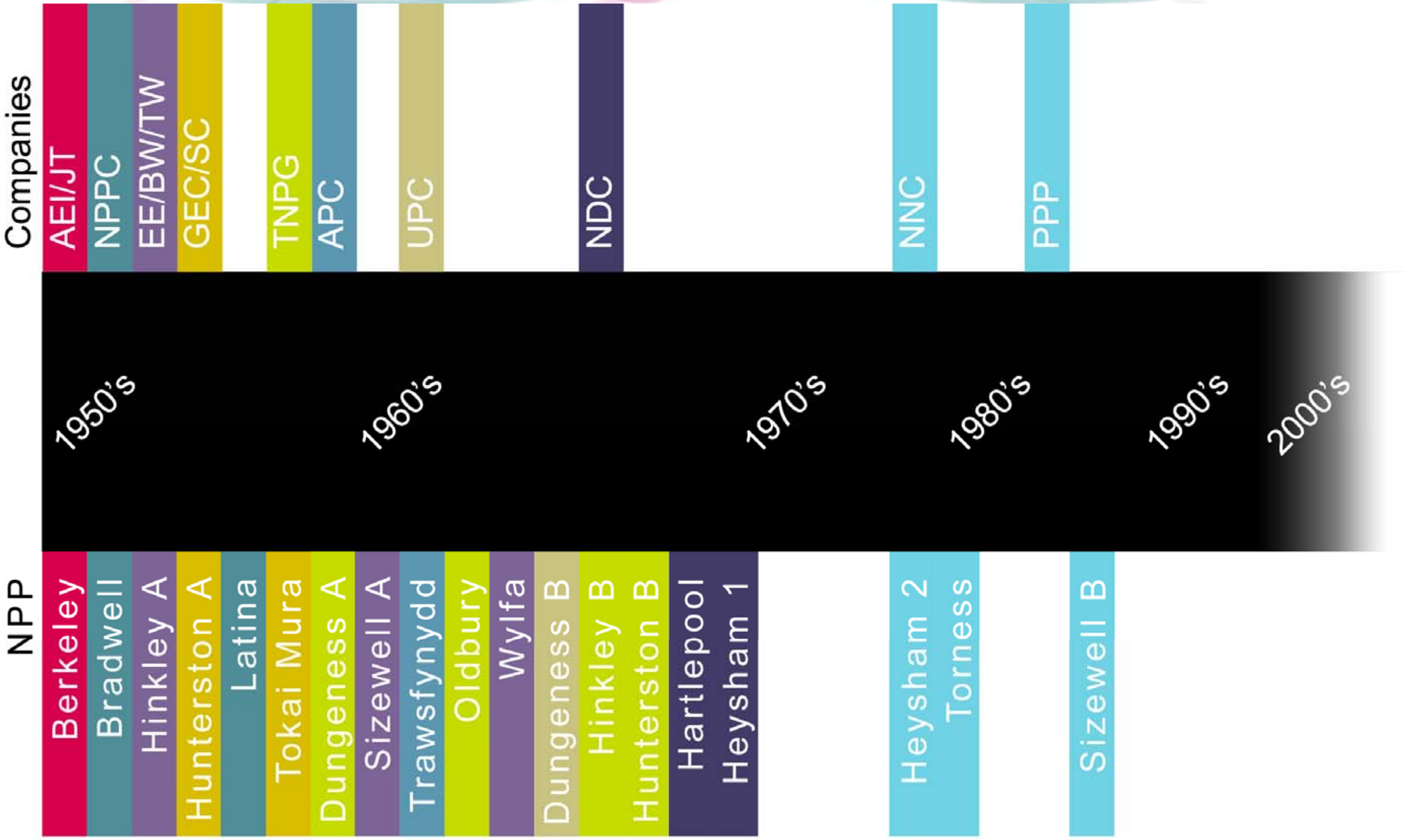
Power and Process

- **Americas** – designs, delivers and maintains plant for power sector and process industries such as pulp and paper, food, alternative fuels and cement
- **UK/Europe** - high pressure gas import terminals, storage & transmission; low pressure gas distribution; electricity transmission networks; power generation & process industries (refining, chemicals, pharmaceutical and steel)
- **Nuclear** - provides consultancy, programme management and asset delivery services to clients on both sides of the Atlantic
- **Wind Energy** – wind energy development

Earth and Environmental

- **Earth and Environmental -** consultancy, engineering & project management services

Nuclear build and AMEC



Nuclear - Our history

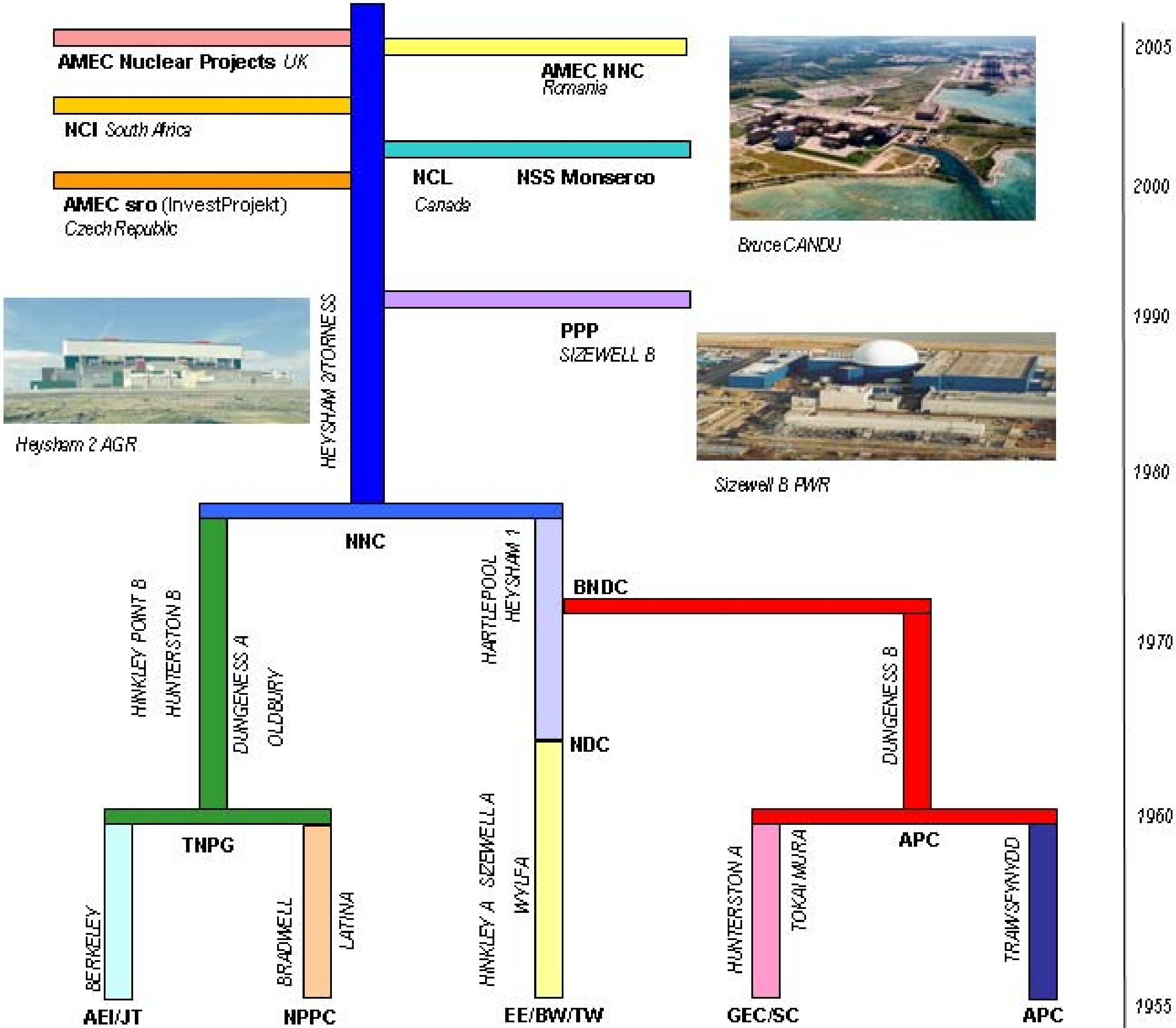

Koeberg PWR


Torness AGR


Heysham 1 AGR


Dungenss A Magnox Reactors


Berkeley Magnox Reactors



Heysham 2 AGR

Bruce CANDU

Sizewell B PWR

New Build

- CONTENTS

- General
- Materials
- Materials Supply Issues

New Build

- GENERAL

- UK Energy Policy Review (2006)
- UK Government - formal backing for the construction of new generation of civil nuclear Power stations (2008)
- UK Health & Safety Executive – 2 stage licensing Process
  - Generic Design Assessment
  - Site License
- BE controls many of the likely sites
- Generic Design Assessment underway (4 designs)
- + 5 years for construction

Gen III – Pressurised Water Reactor

- Originally developed as a US submarine propulsion system:
  - PWR system evolved, particularly in the USA, France and Japan, with similar systems developed in Russia as VVER.
- Uses enriched uranium fuel with zircalloy cladding and water at high pressure as a moderator/coolant
- UK decision taken to finalise the Design and Safety Case before construction, plus lengthy Sizewell 'B' lead station Public Enquiry
- Programme of 5 Replicate PWR stations cancelled

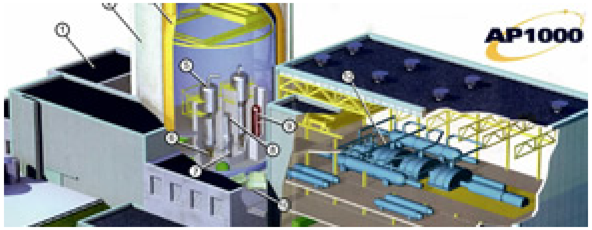
Sizewell B power station

Gen III+
Advanced Light Water Reactors – UK Review for New Build

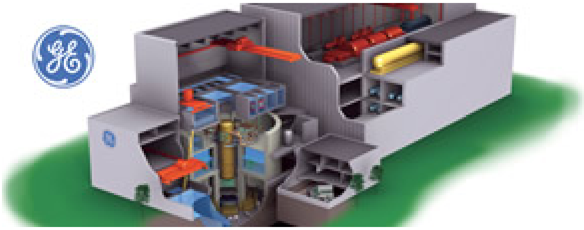
EDF/Areva Evolutionary (European) Pressurised Water Reactor (EPR)

– 1600MWe, 4 loop, 36% efficiency

- **Westinghouse AP1000 PWR**
  - 1100MWe, 2 loop, 33% efficiency



- **GE Economically Simplified Boiling Water Reactor (ESBWR)**
  - 1560MWe, 0 loop, 35% efficiency



- **AECL Advanced CANDU Reactor (ACR-1000): *withdrawn from review***
  - 1165MWe, 520 pressure tubes

New Build

- <u>Materials</u>

- Build on Gen III experience – Sizewell B

- No significant new materials developments

- Established industrial processes

New Build

- Material Supply Issues

- NIA Summary Report - ‘The UK Capacity to deliver a new build Programme’
  - Summary Report
  - Main Report
  - Appendix 3

  Data sheets covering delivery of complete Nuclear Power Station

The UK Capability for New build –Supply Issues 1

- Lack of demand for large power stations in the mid-1990s has led to a decline in the UK manufacturing capability

- Certain specialised components will need to be imported:
    - Heavy reactor pressure vessels
    - Large turbines
    - Steam generators

- UK Supply Chain nevertheless has a strong capability in most of the areas required
    - UK industries could provide 70% of what is required, increasing to 80% with investment & training

- Because of period of no construction - much of the UK experience for engineering and construction is <u>not</u> directly nuclear related
    - Need for non-nuclear industries to become skilled (approved) for Nuclear Supply
    - Important for safety related components

The UK Capability for New build –Supply Issues 2

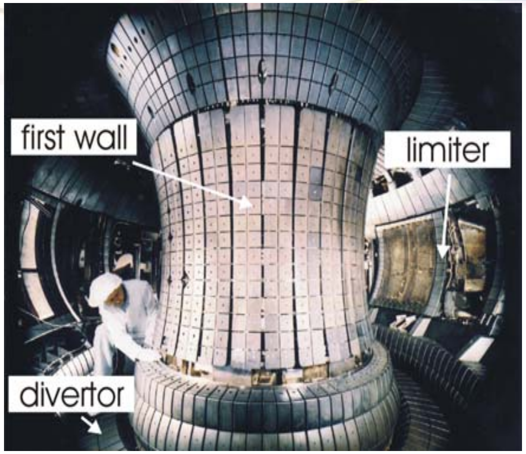
- Currently there are no UK (or Europe) facilities capable of producing large forgings
    - "Sheffield Forgemasters International" Company are in the process of increasing their capability for this supply issue Nuclear 2 - presentation)

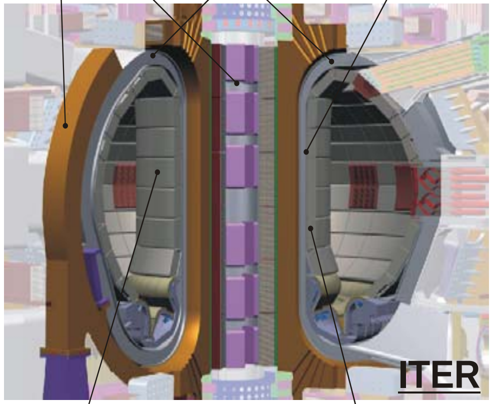
➢ **Forged Nuclear Vessel Components**

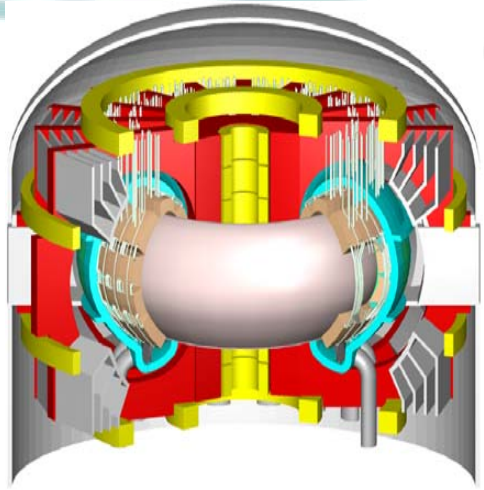
ITER & Fusion

- General
- Materials
- Materials Supply Issues

ITER & Fusion





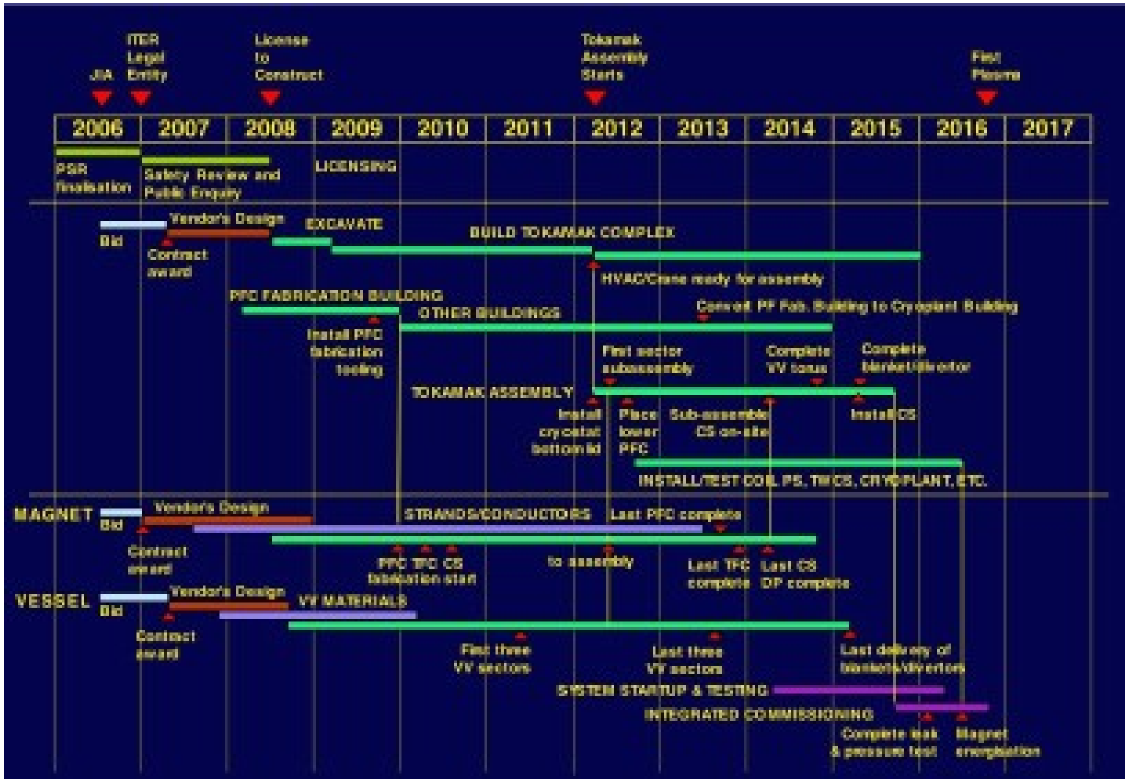


Present tokamaks	ITER	Reactor (DEMO)*
PF surface: < 200 m^2 heating power: <40 MW discharge duration: <60 s	PF surface 687 m^2 alpha p. power 100 MW CD/heating power <73 MW discharge duration: 500 s	PF surface 1300 m^2 alpha p. power 600 MW CD power 120 MW stationary operation

Loading conditions for plasma-facing components

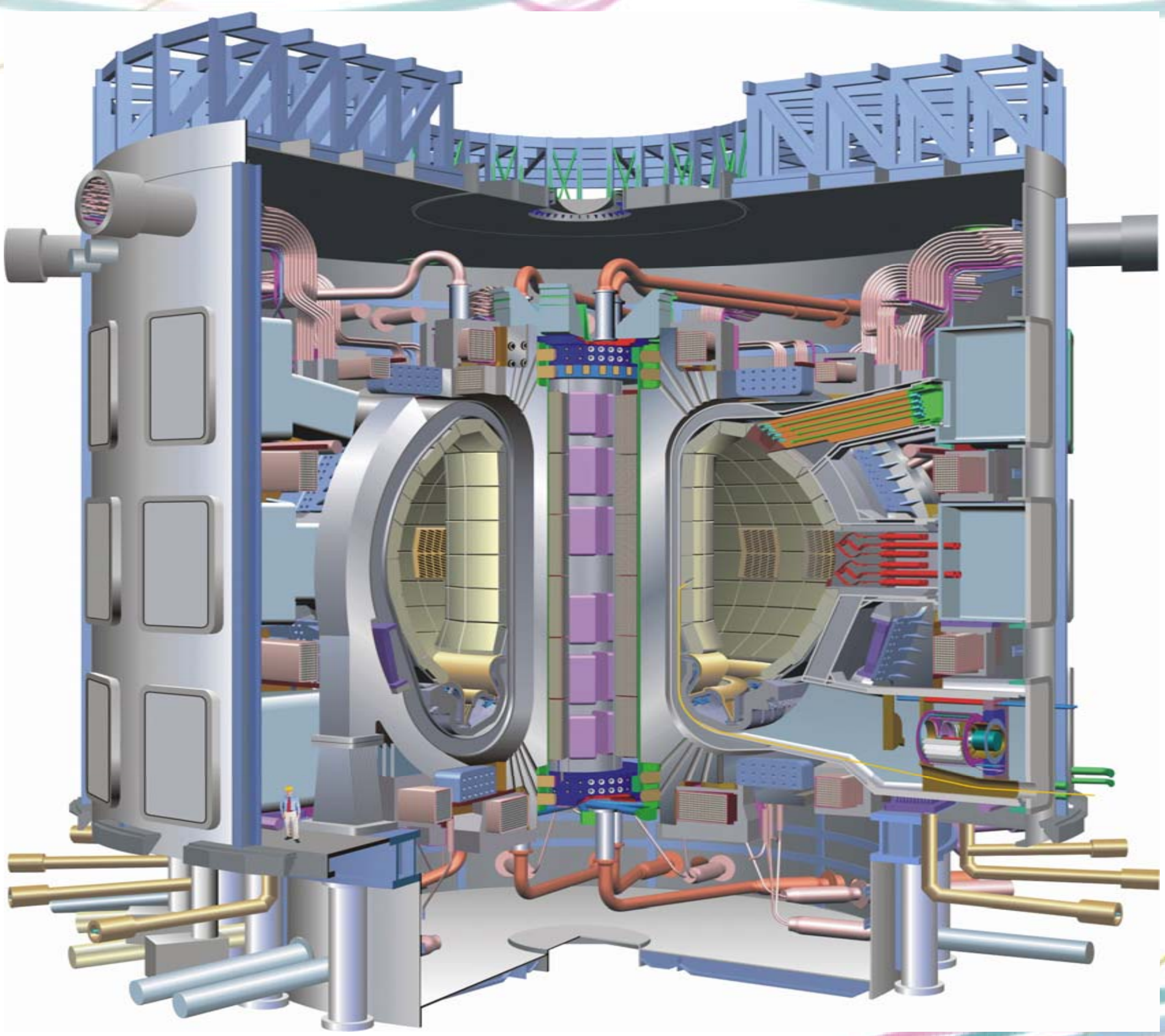
ITER & Fusion

- ITER Construction in France



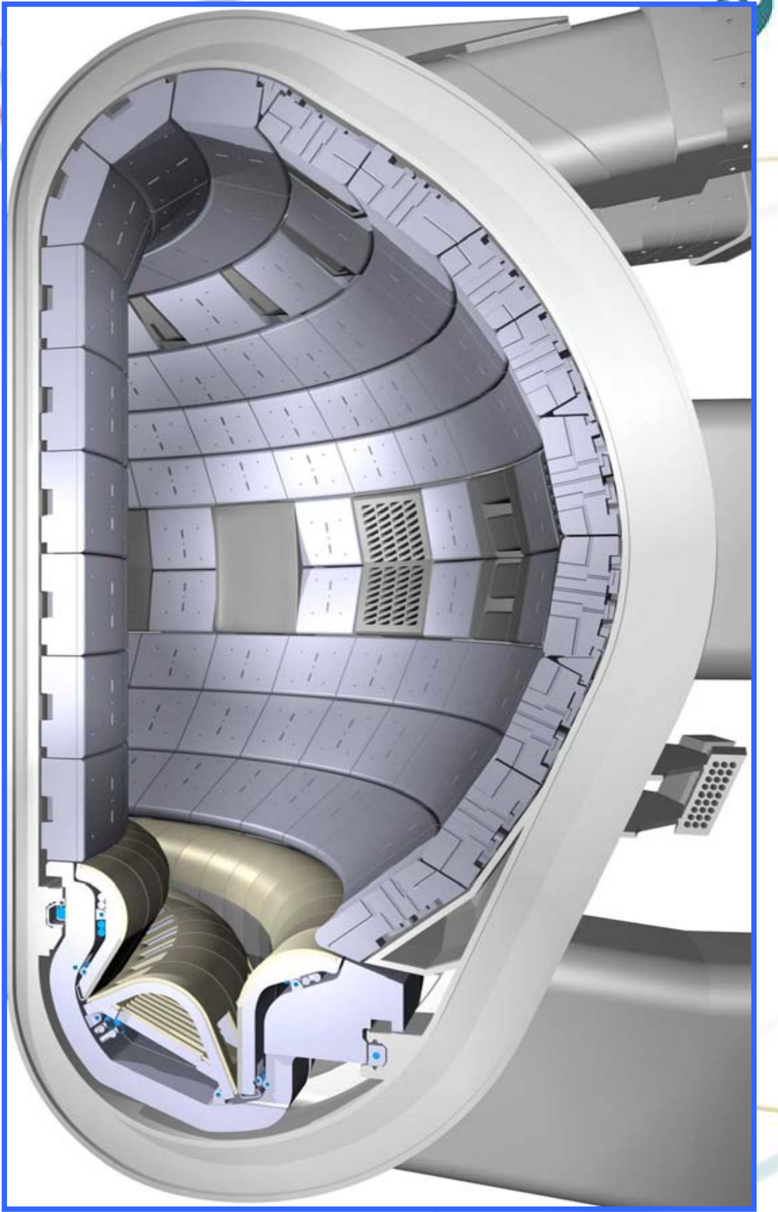
www.iter.org

ITER



Component/Material Summary

- ***All water cooled components***
- ***Vacuum vessel***
  - Stainless steel 316L(N)-IG
- ***Blanket***
  - Stainless steel 316L(N)-IG
  - CuCrZr
  - Beryllium - armour
- ***Divertor***
  - Stainless steel 316L(N)-IG
  - CuCrZr
  - Carbon-fibre composite and Tungsten armour
- ***Limiter***
  - Stainless steel 316L(N)-IG
  - CuCrZr
  - Beryllium - armour



ITER & Fusion

- Specialised Joining Techniques
- Joining techniques include solid HIPping, powder HIPping, brazing and casting based techniques
- The joining of SS/SS, SS/CuCrZr, CuCrZr/Be CuCrZr/CFC and CuCrZr/W have all been developed/adapted for ITER.
- The components are subject to combined mechanical and neutron loadings often under heat loads
- Qualification has been performed by mechanical, neutron and thermal loading.

Fusion Reactors - Supply Issues 1

- Supply issues arise due to geographic concentration of reserves and/or production facilities
- Concerns can be overcome by appropriate design of fusion plant
- Availability and security of supply concerns have been identified for some elements:
    - Minimum required supply of beryllium as a neutron multiplier would exceed known world reserves
    - Vanadium for divertor and blanket structures would tie up a significant proportion of world reserves
        - CFCs strong candidate materials for divertor structures of ITER

Fusion Reactors - Supply Issues 2

- Outstanding resource issues for tantalum and tungsten used in low activation steels
  - Severe shortfalls in the availability of tantalum, an alternative must be found
  - A significant proportion of world tungsten reserves would be tied up in low activation steels re-cycled within the fusion power industry
  - There is a severe lack of 316 LN ITER grade stainless steel for main components of ITER e.g. vacuum wall, shield modules etc.
    - 316 LN ITER grade preferred over conventional 316 stainless steel
    - Currently only 1 company (French) in the world supplies 316 LN ITER grade stainless steel

Generation IV Reactors

- General
- Materials & Manufacturing
- Potential Materials supply Issues

The Evolution of Nuclear Power

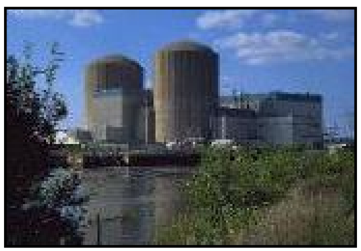
Generation I

Early Prototype Reactors

- Shippingport
- Dresden, Fermi I
- Magnox

Generation II

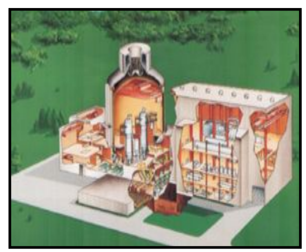
Commercial Power Reactors



- LWR-PWR, BWR
- CANDU
- WER/RBMK
- AGR

Generation III

Advanced LWR's



- ABWR
- System 80+
- AP600
- EPR

Near-Term Deployment

Generation I – III Evolutionary Designs Offering Improved Economics

Generation IV

- Highly Economical
- Enhanced Safety
- Minimal Waste
- Proliferation Resistant

Gen I	Gen II	Gen III	Gen III+	Gen-IV

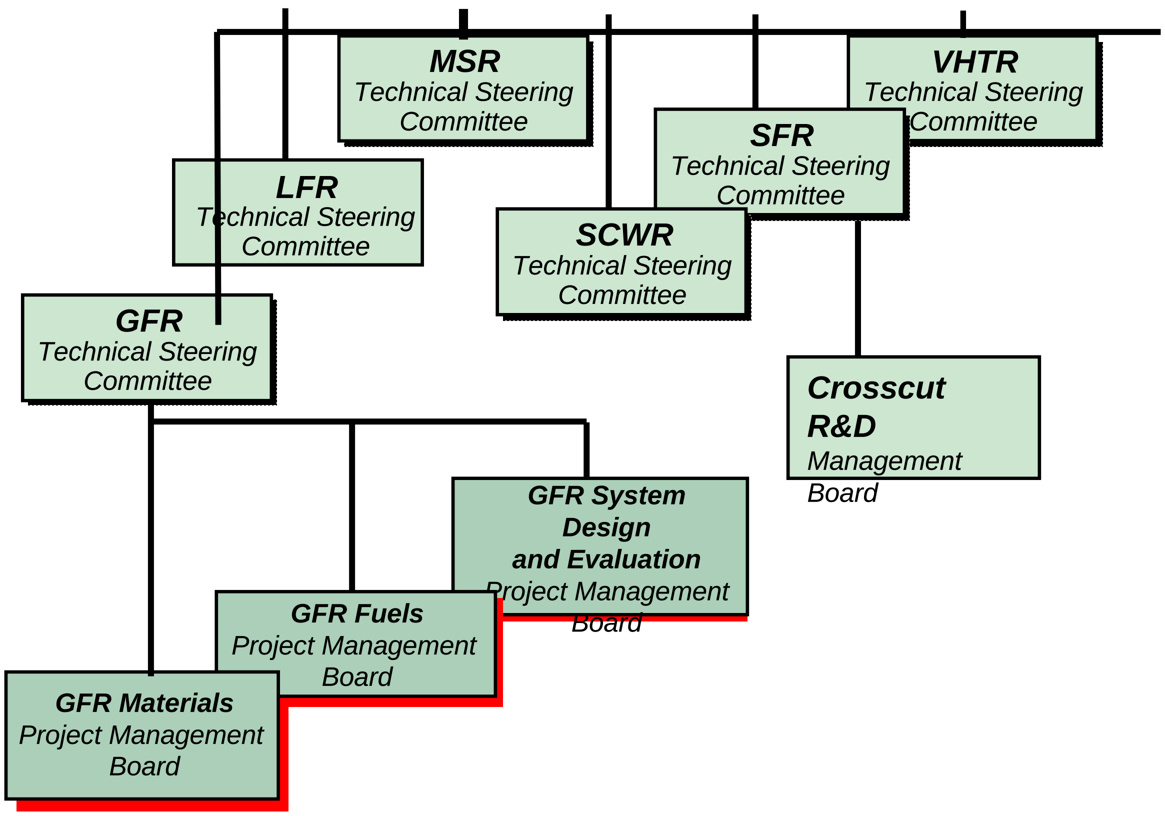
1950 1960 1970 1980 1990 2000 2010 2020 2030

Nuclear Power - Generation IV

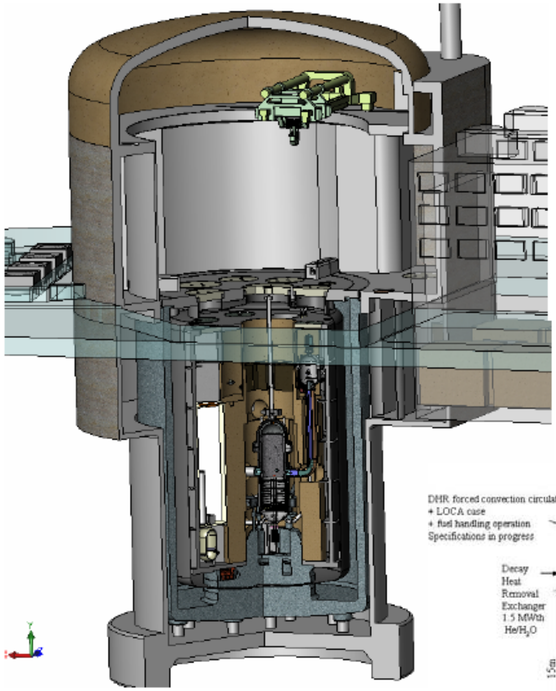
- Generation IV Systems – R & D in progress
- Construction not likely in the UK
- Potential market in China & South Africa (Electricity) also worldwide – processes involving supply of heat
- Industrial deployment >2030

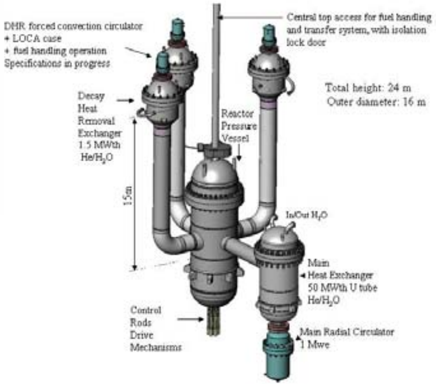
Nuclear Power - Generation IV (GIF)

GIF Systems

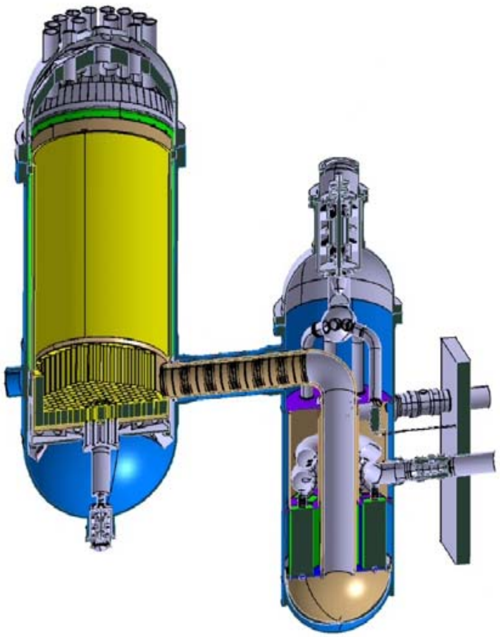


Example - Helium Cooled Gas Reactors





GCFR - ETDR



VHTR - ANTARES

Generation IV

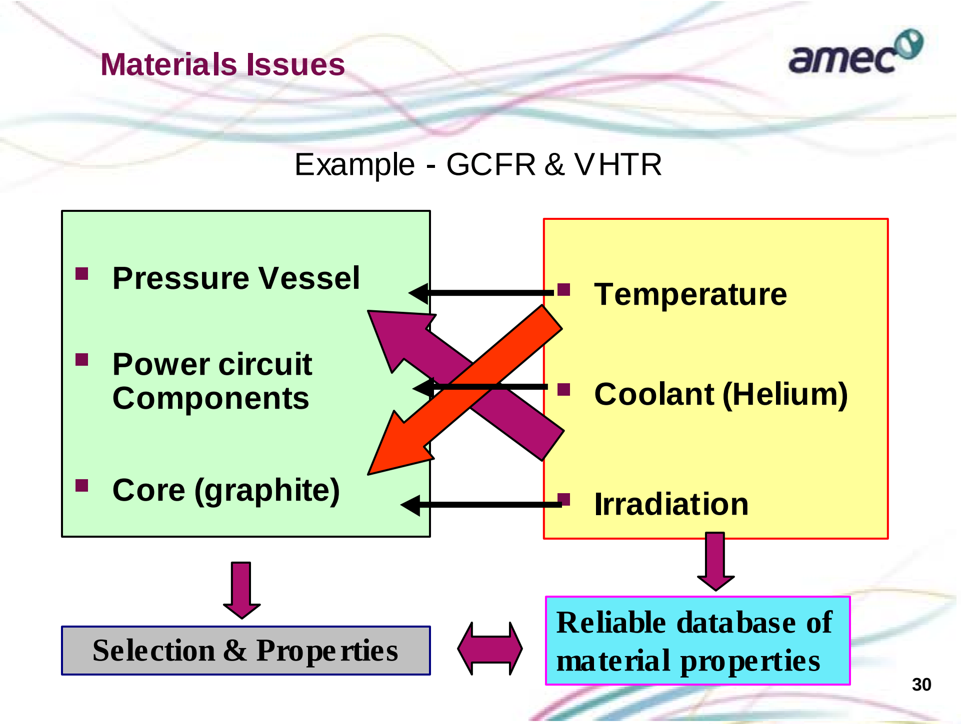
- <u>Materials</u>

- Build on Gen III experience + Fusion

- Likely to feature new materials developments

- Established industrial processes + new processes

- Codes & Standards development in parallel

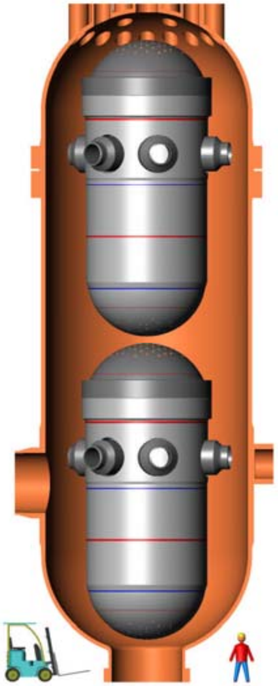


METALLIC MATERIALS

- extending application of existing materials – example VHTR

- Qualification issues
- Base materials & weldments
- Manufacturers & manufacturing
- Codes & procedures

- Programme that takes full benefit of LWR/AGR experience
- Material composition
- Fabrication processes – larger forging – welding -
- Environment – aging - irradiation – corrosion –
- Properties – high temperature
- Fracture resistance
- Inspection issues
- Manufacturer
- Design Codes



Thick section welding

Weld strength

LWR type Vessel steel

LWR experience provides filler materials

Toughness properties well matched

Irradiation embrittlement - less than 1dpa as for LWR – low P & Cu

Thermal aging embrittlement- most likely in HAZ - only for transients at higher temperatures (10 to 100's hours)

Carburisation / Corrosion –

HTR gas chemistry

NEW VESSEL MATERIAL

Mod 9Cr 1Mo steel

No previous experience on thick section RPV welds -

Short term strength - HAZ
long term strength by Type IV cracking

Irradiation embrittlement – increases with lower temperature – no data on welds

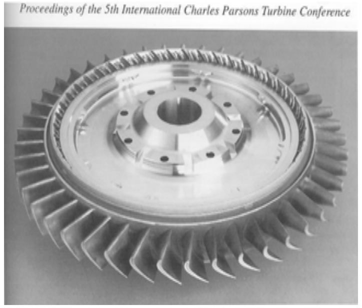
Thermal aging embrittlement – operation above 450ºC - no data on welds

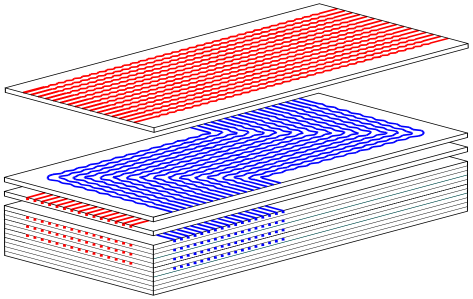
Carburisation / Corrosion- HTR gas chemistry

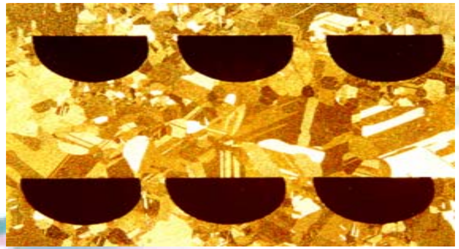
METALLIC MATERIALS

- Developing New Materials & processes – Example VHTR

- **Requirements for very high temperatures**
- Established materials operate up to 750 - 850ºC (reactor experience)
  - Extend the temperature range to +950ºC
- **Requirements for Ni based alloys**
  - Heat Exchanger Materials – Tube & shell /Plate design
    - (IN 617, Haynes 230,...)
  - Hot Gas Duct (Alloy 800)
  - Turbine Materials – Direct Cycle:
    - Disc - Udimet 720 (max 700-750ºC)
    - blades- IN 792 DS & CM 247 LC DS (Al & Cr formers)
- **New Processes**
  - Welding Processes (Diffusion Bonding)
  - Forming Processes (Hipping, powder metallurgy,)
  - Inspection procedures inc. ISI
- **New Materials**
  - Oxide Dispersion Strength (ODS) Materials – higher creep strength but difficult to form & fabricate







NON-METALLIC MATERIALS

- Developing New Materials – Example VHTR

Graphite Qualification – Reactor Core

Difficulties in supply - amount of nuclear grade graphite manufactured worldwide is relatively small

- **Two prototype HTRs (HTTR in Japan, and HTR-10 in China) – use IG110 which is only suitable for replaceable components**

- **Knowledge of properties under Irradiation – key requirement**
- Graphite behaviour in a reactor environment has been extensively studied since the early 1940s – **Good understanding- AGR's**

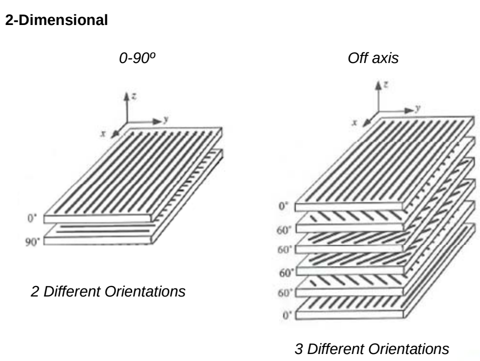
- **Almost all previously irradiated graphites are no longer available**
- Currently there is no way of predicting irradiation behaviour based on unirradiated properties

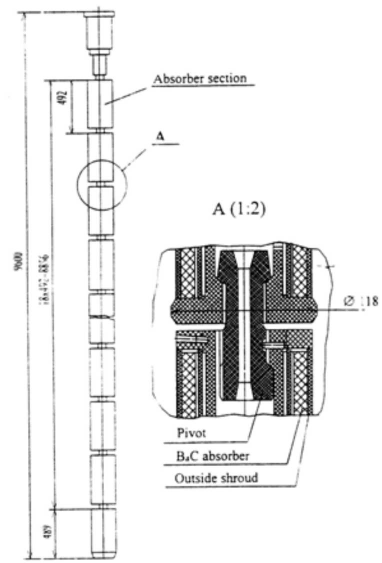
New Graphite material

Carbon Fibers composites (CFC) in HTR / VHTR:

Control rods - cladding

Characterizations of CFCs in order to check their behavior under irradiation and oxidation at high temperature





Supplier needs to work closely with R& D /Design & Constructor –

Generation IV - Supply Issues

Example VHTR

- Material limits reached
- Construction in US NGNP – established materials - 2020
- In Europe - drive to assess Near Term opportunities in heat supply industries – challenge
- Long Term - new materials developments needed
  - Metallics & processes
  - Non-metallics
- Close co-operation with potential suppliers – R & D

Nuclear Power

- Conclusions
- New Build:
  - UK Supply Chain has a strong potential - in most of the areas required
  - UK Companies need to re-instate their Nuclear capabilities
  - Limited World capacity to produce some of the critical components – large forgings, Reactor Pressure Vessel, Generators, Turbines
- ITER & Fusion
  - Opportunity for UK Companies
  - Concerns on availability & supply of certain specialised materials :
    - Beryllium; vanadium; tantalum
    - 316L (N) Stainless Steel : French Supplier
- Generation IV
  - New materials developments - joint R & D activitiies
  - Non-metallics - close co-operation with potential suppliers