Materials Supply Chains in the UK Power Generation Sector

Nuclear Power (1)

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AMEC at a glance

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

Workshop on Materials supply chain issues for UK Power Generation Sector
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
CONTENTS

- General
- Materials
- Materials Supply Issues
GENERAL

- 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

- **Materials**

- Build on Gen III experience – Sizewell B

- No significant new materials developments

- Established industrial processes
- 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
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 not directly nuclear related:
- Need for non-nuclear industries to become skilled (approved) for Nuclear Supply
- Important for safety related components
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
Present tokamaks
PF surface: < 200 m²
heating power: <40 MW
discharge duration: <60 s

ITER
PF surface 687 m²
alpha p. power 100 MW
CD/heating power <73 MW
discharge duration: 500 s

Reactor (DEMO)*
PF surface 1300 m²
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
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
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.
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.
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

Timeline:
- Gen I: 1950-1960
- Gen II: 1970-1980
- Gen III: 1990-2010
- Gen III+: 2020-2030
- Gen-IV: 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
GIF Systems
Example - Helium Cooled Gas Reactors

GCFR - ETDR

VHTR - ANTARES
Generation IV

- **Materials**

- Build on Gen III experience + Fusion

- Likely to feature new materials developments

- Established industrial processes + new processes

- Codes & Standards development in parallel

Example - GCFR & VHTR

- Pressure Vessel
- Power circuit Components
- Core (graphite)
- Temperature
- Coolant (Helium)
- Irradiation

Selection & Properties

Reliable database of material properties
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

**NEW VESSELS MATERIAL**

LWR type Vessel steel
LWR experience provides filler materials
Toughness properties well matched
Irradiation embrittlement - less than 1 dpa 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

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 450°C - no data on welds
Carburisation / Corrosion- HTR gas chemistry

**Thick section welding**

**Weld strength**
METALLIC MATERIALS
- Developing New Materials & processes – Example VHTR

- Requirements for very high temperatures
  - Established materials operate up to 750 - 850°C (reactor experience)
    - Extend the temperature range to +950°C
- 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 700-750°C)
    - 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

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

New Graphite material

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-metals
- Close co-operation with potential suppliers – R & D
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 activities
- Non-metallics - close co-operation with potential suppliers