Fusion material challenges

UK Atomic Energy Authority

Harnessing fusion energy is a demanding process and requires materials that can cope in extreme environments. Some of the challenges faced are:

- **Materials** used in the fusion reactor are expected to be **low-activity**, meaning that when reactors are shutdown, they **can be dismantled** and **disposed** of relatively **rapidly**, **without** the risk of radioactive **contamination**. This limits the elements that we can use, **necessitating new materials** to be utilised.
- The new materials generally **require nuclear qualification** and need to **establish supply chains**. Developing the qualification, regulation and industrial supply chain for these materials represents a **key challenge to commercial fusion power**.
- The **engineering challenges** of fusion often necessitate **complex component cooling, use of multi-material interfaces and complex shaping**. Materials utilised must accommodate these advanced design requirements.
- **Material** facing the plasma generated during fusion operations may require **prolonged operation** at temperatures in **excess of 1000°C**.
- **Materials** inside the toroidal magnets of a fusion reactor may experience **high magnetic fields** (>10T) and must be **tested to validate operation** under these conditions.
- **Neutrons** generated during the fusion reaction **cause the structure of materials to change**. In some cases, atoms are rearranged hundreds of times because of neutron bombardment during the lifetime of the reactor.
- **Materials** coming into contact with plasma causes **material erosion**.
- **Liquid lithium** will be contained within fusion blanket materials to allow for tritium generation – a fuel required for the fusion reaction. Exposure of metals to liquid lithium **often negatively affects their properties**.

It is clear that a **specialised** range of **materials** will be **required** to meet these challenges. The Material Technology Laboratory is always looking for **future materials** which may offer **superior properties**, but a selection of leading candidate materials we already use and study are:

- **Reduced Activation Ferritic Martensitic (RAFM) Steels** – RAFM steels are considered the **primary candidate** for most fusion breeding blanket designs and internal piping for DEMO fusion reactors. These are reduced activation 9%Cr steels, akin to P91 grade steels with elemental substitution such as **EUROFER97** .
- **Nano-strengthened steels** – MTL are also looking into **oxide dispersion strengthened** (ODS) variants of EUROFER97, 14%Cr ODS steels and cast nano-precipitate strengthened steels. These materials offer **superior high temperature performance** compared to conventional RAFM steels, but with a **less mature supply chain**.
- **Tungsten** – with a melting point in excess of 3400°C, tungsten is **well-suited to a plasma-facing role** in the first wall blanket. It is also **less susceptible to plasma erosion** than other candidate materials. However, at temperatures **below 400°C, tungsten is brittle**. Thus tungsten design is challenging. The **industrial supply chain** for high quality and reproducible tungsten production is **not yet established**.
- **Copper-Chromium-Zirconium** – or more accurately Cu-1.0%Cr-0.1%Zr – is considered the **primary candidate** for the **water-cooling pipes** for the divertor within a fusion reactor.
- **Vanadium-Chromium-Titanium** – otherwise known as V44, V-4%Cr-4%Ti – is recognized as an **attractive structural material for the liquid lithium** blanket of a demonstration fusion reactor (DEMO), because of its **good** levels of **high temperature strength, creep resistance, irradiation tolerance** and a **relatively low ductility loss** due to radiation-induced defects. **Vanadium** itself is also a **very low activating element** within the blanket environment, providing a **significant advantage** in **decommissioning** and remote handling of components. Presently there is **no industrial supply chain or infrastructure** that can produce the tonnage of V44 that would be required by fusion reactor designs.