Key materials for nuclear power generation

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Abstract: As a clean, economic and sustainable development of energy, nuclear power was increasingly rose by the whole world. Nuclear power industry is inseparable from the development of nuclear materials. Any breakthrough in nuclear technology depends on the first breakthrough in nuclear materials. This paper will introduce the key nuclear material, including nuclear fuel, cladding materials and structural materials.

1. Introduction

Since the 1980s, the world's energy consumption rose sharply and the fossil fuels such as oil, gas and coal have been unable to meet the long-term needs of world economic development. With the global environmental deterioration and the people of all countries to strengthen of environmental protection consciousness, resulting in a large number of harmful gases and waste of the traditional energy industry has become increasingly difficult to meet the requirements of the development of human society.[1] In the face of such a severe energy situation, based on the analysis of the different development potential and application status of various new energy sources, we choose to choose nuclear power as an important strategic target for the development of new energy sources.

2. Nuclear power

Nuclear power is the energy use of nuclear fission in nuclear reactors released by the power , it is an important way to realize the low carbon power generation. The nuclear power generation uses the heat generated by the nuclear fission reaction, and the water is heated to high temperature and high pressure. [2] Thus, the steam turbine is driven to rotate and achieve the power generation. The heat emitted by the nuclear reaction is much higher than that of the fossil fuel (about a million times more), and the amount of fuel needed is much less than that of a thermal power plant. For example, the nuclear power plant uses 50 tons of nuclear fuel every year, as long as the standard container can carry 2. If you want to replace nuclear with coal, 5 million 150 thousand tons was needed, with 20 tons of large trucks to 705 vehicles every day.[3]

3. Nuclear material and its characteristics

Nuclear materials include nuclear fuel, cladding materials and structural materials. Nuclear power industry is inseparable from the development of nuclear materials. Any breakthrough in nuclear technology depends on the first breakthrough in nuclear materials. The gap between China and developed countries in nuclear material is mainly reflected in the overall performance of the material cannot meet the requirements of the development of nuclear power plants, the performance data is not complete, the material, the variety is single, the basic research of the material is not enough, the economical efficiency to be further improved.[4] Nuclear materials have become one of the bottlenecks restricting the development of new nuclear power plants.

3.1. Nuclear fuel

Nuclear fuel is a substance that produces fission or fusion nuclear reactions and releases a large amount of nuclear energy。 Nuclear fuel into fissile fuel and fusion fuel (or thermonuclear fuel) two

categories。Fissile fuel which containing fissile nuclides in the reactor can achieve self-sustaining nuclear fission chain reaction materials, mainly U235, Pu239, U233.[5]

3.2. Cladding material

As a fuel rod cladding material, stainless steel has been replaced by Zr-4 alloy because of its large thermal neutron absorption cross section。The use of Zr-4 instead of stainless steel as fuel cladding material can save about 1/2 of uranium fuel。The corrosion resistance and strength of high temperature water and steam are greatly improved by Zr-4. and the hydrogen absorption of Zr-4 is much smaller than that of Zr-2。The disadvantage of Zr-4 alloy is that the oxide film is not dense and easy to fall off. So, cladding material Zr-4 alloy cannot be used as high burnup fuel。The M5 system of Zr-Nb alloy developed in France, the Nb in the alloy has the self-healing ability to the oxide film fall off, and it is superior to Zr-4 alloy in corrosion resistance, creep, irradiation growth and hydrogen absorption. The M5 alloy can be used under the condition that the fuel consumption is greater than 65GWd/tU, and has been applied to the fuel rod cladding of the European advanced pressurized water reactor (EPR). Zirlo alloy which developed by Westinghouse Electric Corporation combines advantages of Zr-Sn and Zr-Nb alloy. Under the condition of 71GWd/tU burnup, the uniform corrosion rate, irradiation growth and creep properties of Zirlo alloy are better than that of Zr-4 alloy.[6]

3.3. Structural materials

3.3.1 Steel used in primary circuit

The main circuit of the primary circuit is an important barrier to prevent the fission products of nuclear reaction from leaking into the containment when the nuclear power plant under normal, abnormal, accident and test conditions. T Therefore, the main nuclear power pipeline to be able to withstand high temperature, high pressure and corrosion resistance. The primary circuit of third generation pressurized water reactor nuclear power plant AP1000 using 316LN austenitic stainless steel forging. And this kind of steel is a kind of extra-low carbon and nitrogen controlled austenitic stainless steel. This kind of steel is adding nitrogen on the basis of 316L, which can improve the strength of the material, while still maintaining a high level of plasticity and toughness.

3.3.2. Steel for pressure vessel

In the middle of 1960s, A533B was added to the A302B steel to develop better hardenability and toughness. On the basis of A508-Ⅱ steel, the A508-Ⅲ steel has been improved by decreasing the content of C, Cr (Cr), Mo, and increasing the content of Mn, which is the preferred material for large pressure vessel.[7]

3.3.3. Steel for steam generator

The shell of the steam generator, which comprises an upper head, an upper cylinder, a lower cylinder and a cone body, is made of ferritic steel plates; U type heat transfer tube in the past using 18-8 stainless steel, has been widely used 690, 800 Ni base alloy; The tube plate is made of high strength low alloy steel, and the coolant side of the first loop is stainless steel surfacing layer.

3.3.4. Steel for pile internals

In the second generation PWR nuclear power plant, the main material in the reactor is austenitic stainless steel such as 304L、304LN、321、347、310. And the Bolt material is 316LN, 321H stainless steel. Some special parts are made of martensitic stainless steel, such as compression spring. The third generation pressurized water reactor (AP1000) nuclear power plant has more power and longer life, so it is more strict to the composition and performance of the reactor internals. The main structural material is made of forged F304 and F304H austenitic stainless steel and the improved 403 martensitic stainless steel is used for the compression spring.

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