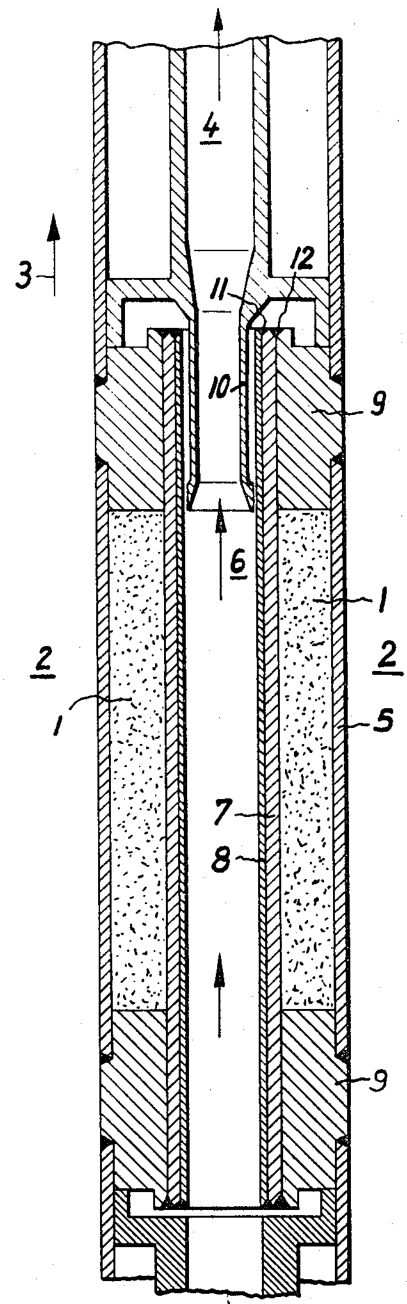
May 21, 1968 H. KORNBICHLER 3,384,551

FUEL ELEMENT HEAT TRANSFER ARRANGEMENT

Filed Feb. 17, 1966



Inventor:
Heinz Kornbichler
By: Spencer & Kaye
Attorneys

United States Patent Office

3,384,551
Patented May 21, 1968

3,384,551
FUEL ELEMENT HEAT TRANSFER ARRANGEMENT

Heinz Kornbichler, Falkenstein, Taunus, Germany, assignor to Licentia Patentverwaltungs G.m.b.H., Frankfurt am Main, Germany

Filed Feb. 17, 1966, Ser. No. 528,306
Claims priority, application Germany, Feb. 17, 1965, L 49,979
4 Claims. (Cl. 176—67)

ABSTRACT OF THE DISCLOSURE

A cladding arrangement for protecting a tubular fuel element and including an inner jacket covering the inner surface of the fuel element, a corrosion resistant metal layer covering the first jacket, a second jacket covering the outer surface of the fuel element, and a sealing plug disposed at each end of the fuel element for sealing off the ends thereof, the jackets and plug all being made of a material having a low ratio of neutron absorption to mechanical strength at the temperatures to which the fuel is to be raised.

The present invention relates to the field of heat generation, and particularly to fuel elements for nuclear reactors.

For use in nuclear reactors employing water or steam as a primary coolant, ceramic fuel elements provided with metallic cladding have come to find general application and acceptance. The cladding material must meet the following two primary requirements: (1) it must be corrosion-resistant under the normal operating conditions of the reactor; and (2) it must have the smallest possible neutron capture cross section, i.e., the ratio of neutron absorption per unit of volume to the mechanical strength of the cladding should be a small as possible.

It has been found that the first requirement of corrosion resistance is satisfied, under the conditions existing in a boiling water reactor moderator, quite well by Zircaloy and moderately well by the higher nickel-containing alloys. Under certain conditions, it is not completely satisfied by stainless steel of the 18–8 series (i.e., having a base of 18% Cr and 8% Ni). For exposure to a vapor primary coolant which creates wall temperatures of up to 650° C., the corrosion resistance requirement is satisfied quite well by the higher nickel-containing alloys, but not as well by stainless steel of the 18–8 series and, at the present time, not at all by the currently available types of Zircaloy.

It has also been found that the requirement relating to a low neutron capture cross section is satisfied best by Zircaloy, fairly well by stainless steel of the 18–8 series, and poorly by the higher nickel-containing alloys.

Thus, a simple envelope made of one of the above-mentioned materials, such as stainless steel for instance, can not satisfy both of the above-noted conditions to a satisfactory degree.

It is therefore an object of the present invention to eliminate these shortcomings.

It is another object of the present invention to provide improved cladding for fuel elements.

A more specific object of the present invention is to provide improved cladding for ceramic fuel elements.

Still another object of the present invention is to provide a fuel element cladding which has both a high corrosion resistance and a low neutron capture cross section.

The novel advantages of the present invention are realized by the provision, in connection with a fuel element for heating a primary coolant vapor to a predetermined temperature in a reactor, of a cladding arrangement including a first jacket made of a metal having a low ratio of neutron absorption to mechanical strength at temperatures in the region of the predetermined temperature. This jacket covers the surface of the fuel element which is adjacent the region occupied by the primary coolant vapor. Also, there is a layer made of a metal which has a high resistance to corrosion at such predetermined temperature, this layer covering the surface of the jacket which faces the region occupied by the primary coolant vapor.

In accordance with another feature of the present invention there is provided a second jacket made of a zirconium alloy fitted around the outer surface of the fuel element for mechanically supporting the same.

According to still another feature of the present invention there is also provided a sealing plug at each end of the fuel element for sealing off the fuel element, this plug being made of the same material as the jacket and being welded to both the first jacket and the second jacket.

Yet another feature of the present invention resides in the provision of a thermal protective cap made of a corrosion-resistant material disposed adjacent that end of the inner jacket through which the primary coolant vapor exits for isolating this end of the jacket and the weld disposed at this end from the heated primary coolant vapor.

Additional objects and advantages of the present invention will become apparent upon consideration of the following description when taken in conjunction with the accompanying drawing wherein the single figure of the drawing is a longitudinal, cross-sectional detail view of a portion of a preferred embodiment of the present invention.

The figure shows a preferred embodiment of the present invention wherein the fuel element **1**, which may be made of uranium dioxide for example, has a tubular configuration and is arranged to be surrounded by a mass of boiling water in the region **2**, it being intended that this boiling water be maintained at a temperature of approximately 285° C. The saturated vapor, or steam **3**, into which the boiling water in the portion of region **2** adjacent the fuel element is converted by the heat generated in the fuel element is conveyed into the central region **6** within fuel element **1** by any suitable, well-known vapor supplying system (not shown). This vapor is further heated during its passage through the central region of the fuel element and exits from the region **4** as superheated steam. The outer circumference of fuel element **1** is enclosed by an encasing tube **5** made of a suitable zirconium alloy which acts as a mechanical support for the fuel element. The inner surface of the fuel element is isolated from the high temperature vapor in the region **6** by a double tube **7**, **8**. This double tube consists of a tube **7** which may be made of Zircaloy, for example, and an inner, thin metallic tube or coating **8** which may be made of Incoloy, for example. The coating **8** serves to prevent corrosion of the tube **7**.

In further accordance with the present invention, the fuel element **1** is provided at each end with an annular sealing plug **9** which is also made, for example, of Zircaloy, and to the inside of which there is disposed a thermal protective cap **10**. In the illustrated embodiment, this protective cap is integral with a further tube portion which serves to convey superheated steam leaving the region **6** of fuel element **1** out of the reactor.

Given the properties of the cladding materials discussed above, it would seem that a highly satisfactory jacket for the fuel element **1** could be constructed by covering the outer surface of the fuel element with a sheath made of Zircaloy, this material having a low neutron capture level and good corrosion resistance to the boiling water in the region 2, and by covering the inner surface of the fuel element with a sheath made of one of the higher nickel-containing alloys, such as Incoloy, for example, which would have a highly satisfactory corrosion resistance to the superheated vapor present in the region 6. However, it has been found that a serious obstacle exists to such a form of construction because of the difficulty of welding zirconium to steel. Even if this problem could be solved satisfactorily, the great difference existing between the coefficients of thermal expansion of the two metals would cause a considerable amount of stress to be created between the outer sheath and the inner sheath and would thus produce serious difficulties. In addition this inner sheath of a higher nickel-containing alloy would have to be so thick, for structural reasons, as to have an unsatisfactorily high neutron capture cross section.

However, these problems are eliminated in arrangements constructed according to the present invention by manufacturing both tubes 5 and 7, as well as the sealing plugs 9, of the same material, such as Zircaloy, for example. It thus results that thermal stresses will not be created between the inner tube and the outer tube due to differing coefficients of thermal expansion, any stresses which do arise being the result only of a temperature differential between the region 6 and the region 2. However, because the coefficient of thermal expansion of Zircaloy is very low this temperature differential will only create relatively small thermal stresses in an arrangement constructed according to the present invention. At the same time, the metallic coating 8 will prevent the superheated vapor in the region 6 from corroding the Zircaloy tube 7.

When employing an arrangement according to the present invention in which the Zircaloy tube covering the inner surface of the fuel element is provided with a corrosion-resistant coating or tube to prevent the Zircaloy from being corroded by the superheated steam in the region 6, one problem which arises is that the exposed ends of the Zircaloy tube might be contacted, and hence corroded by the superheated vapor. This problem is avoided by another feature of the present invention according to which the inner Zircaloy tube is welded, at each end, to the annular sealing plug 9 and also to the corrosion resisting tube 8 to form the welding seams 12 and 11, respectively. It should be noted that the welding seam 11 between the layer or tube 8 and the Zircalogy tube 7 need not have any substantial structural strength and serves merely to seal the joint between the tubes 7 and 8 in order to prevent vapor from penetrating into the annular region therebetween. No great difficulties are encountered in forming such a weld between zirconium and steel, even when the steel is constituted by one of the higher nickel-containing alloys, because, as has been noted above, this weld need not have any substantial structural strength.

Furthermore, in order to prevent the weld itself and the end face of the Zircaloy tube from being affected by the super-heated vapor, there is provided, in further accordance with the present invention, the thermal protective cap 10 which extends to the inside of, and along, the upper end of the arrangement of tube 7 and tube or coating 8 in order to permit only a small percentage of the superheated steam to reach the region adjacent welds 11 and 12. Because Zircaloy is a good conductor of heat, and because the temperature at the outer surface of the arrangement is substantially lower than that in the region 6, it results that the region adjacent the welds 11 and 12 is maintained at a temperature which is not substantially higher than that of the boiling water occupying the region 2. It is known that Zircaloy is highly resistant to corrosion at these temperatures. Because the weld 12 is formed between two bodies of the same material, this weld is capable of withstanding high stresses.

Because the provision of the thermal protective cap 10

permits the weld 11 to be maintained substantially at the temperature of the boiling water in the region 2, this protective cap offers the further advantage that the weld 11 is not subjected to the frequent temperature variations to which the vapor in the region 6 is subjected when the fuel element is cycled between a full load and a no-load state. Such cycling may often cause the temperature of the vapor in the region 6 to fluctuate between a temperature of 500° C. and a temperature of 300° C., for example. Such cycling often takes place daily and even more frequently in the operation of a power plant.

However, the seam 11 will be subjected to a large temperature change if the power plant is brought to a complete halt, its temperature then possibly changing from 300° C. down to 60° C. However, temperature variations of this type only occur every few months during normal power plant operation.

In accordance with another feature of the present invention, the element 8 may be constituted by a tube, and the tubes 7 and 8 can be assembled together merely by inserting the tube 8 into the tube 7. It is of course desirable that the tubes fit together very closely so that a very low resistance to heat conduction will exist between them. To this end, it would be particularly advantageous to construct the assembly of tubes 7 and 8 by inserting a bloom of the material from which the tube 8 is to be made into a hollow bloom of the material from which the tube 7 is to be made, and by simultaneously drawing the two blooms in a suitable drawing, or extrusion, apparatus to give the tubes their final desired dimensions. It is well known that such a technique permits the corrosion-resistant tube 8 to be drawn to an extremely small thickness. Moreover, such a drawing operation permits a true metallurgical bond to be created between the two tubes. This bonding can be improved, if desired, by carrying out an intermediate annealing.

It is also possible to provide the element 8 in the form of a coating or layer simply by means of an electrodeposition of nickel or chromium, for example.

By the true and strong metallurgical bond between the thin corrosion resisting cladding tube 8 and tube 7 over the whole area of contact the different coefficients of thermal expansion of both tubes can not cause any effect and thus can not break or disrupt any of the tubes even at their thinnest spot.

Moreover forces of compression and expansion uniformly act on each of the infinitesimal little areas. By this uniformly distributed stress a remarkably higher tensile strength is obtained then if both tubes are welded together only at their frontal line of contact.

For the thermal protective cap 10 Incoloy can be used.

It will be understood that the above description of the present invention is susceptible to various modifications, changes, and adaptations, and the same are intended to be comprehended within the meaning and range of equivalents of the appended claims.

What is claimed is:

1. A cladding structure for covering a nuclear reactor fuel element which has a tubular configuration and which is to be disposed in a reactor in which boiling water is present in the region outside the fuel element and a primary coolant vapor to be heated to a predetermined temperature is present in the region enclosed by the fuel element, said cladding structure comprising:

(a) a first jacket made of a metal having a low ratio of neutron absorption to mechanical strength at temperatures in the region of such predetermined temperature, said jacket being made of a zirconium alloy and covering the inner surface of such fuel element to provide a mechanical support therefor;

(b) a layer made of a metal which has a high resistance to corrosion at such predetermined temperature, said layer covering the surface of said jacket; and

(c) a second jacket made of a zirconium alloy and fitted around the outer surface of such fuel element for mechanically supporting the same.

2. An arrangement as defined in claim **1** further comprising a sealing plug disposed at each end of such fuel element for sealing off the fuel element, said plug being made of the same material as said jackets.

3. An arrangement as defined in claim **1** wherein said first jacket is welded to said layer at each longitudinal end thereof, said arrangement further comprising a thermal protective cap made of a corrosion-resistant material disposed adjacent one end of said first jacket for isolating said end of said first jacket and the weld disposed at said end from the heated primary coolant vapor.

4. A cladding structure for covering a tubular fuel element, which fuel element has an outer jacket and is arranged to heat a primary coolant vapor disposed in the region enclosed by the fuel element to a predetermined temperature, said cladding structure comprising:

(a) a jacket made of a metal having a low ratio of neutron absorption to mechanical strength at temperatures in the region of such predetermined temperature, said jacket covering the surface of such element which is adjacent the region occupied by such primary coolant vapor;

(b) a tube of a metal which has a high resistance to corrosion at such predetermined temperature, said tube covering the surface of said jacket which faces the region occupied by such primary coolant vapor and being welded to said jacket at each longitudinal end thereof; and

(c) at least one thermal protective cap made of a corrosion-resistant material and disposed adjacent one end of said tube and extending into the region enclosed thereby for protecting said end of said tube, the associated end of said jacket and the weld between said tube and said jacket from the heated primary coolant vapor, said cap having a tubular portion which defines a flow passage for the primary coolant vapor.

References Cited

UNITED STATES PATENTS

3,171,789	3/1965	Wanklyn et al.	171—58 X
3,212,988	10/1965	Ringot	176—67
3,291,696	12/1966	Suginoto et al.	171—71 X
3,304,235	2/1967	Granata et al.	176—67 X

OTHER REFERENCES

Nuclear Science Abstracts, vol. 17, No. 6, March 1965, Abstract #10,541, p. 1260.

Nuclear Science Abstracts, vol. 19, No. 10, May 1965, Abstract #18,428, p. 2263.

L. DEWAYNE RUTLEDGE, *Primary Examiner.*

CARL D. QUARFORTH, *Examiner.*

M. J. SCOLNICK, *Assistant Examiner.*