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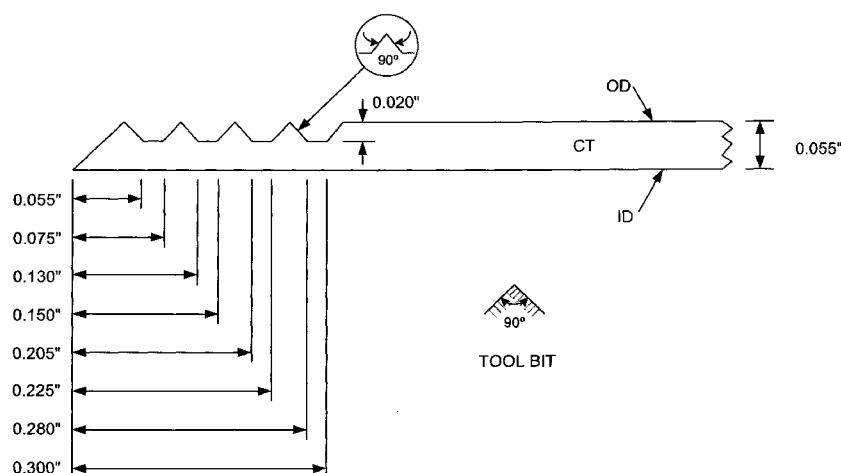
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[Continued on next page]

(54) Title: CALANDRIA TUBE JOINT

FIGURE 10

FOUR CONCENTRIC GROOVES – SERRATED CT



(57) Abstract: The present invention relates to a method of refurbishing calandria vessels in nuclear reactors, and more specifically, to a method of fastening calandria tubes to a tubesheet plate in a calandria when refurbishing a nuclear reactor. A method of refurbishing a calandria is described, comprising the steps of: forming circumferential cuts/serrations/grooves on the outside diameter of a calandria tube; and expanding/deforming the calandria tube into a bore of a tubesheet plate of the calandria, whereby the sharp edges of the serrations "bite" into the tubesheet plate to provide a leak-tight seal. Other aspects of the invention are also described.

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(15) Information about Corrections:
see Notice of 21 March 2013

Previous Correction:
see Notice of 29 November 2012

Calandria Tube Joint

FIELD OF INVENTION

[0001] The present invention relates to a method of refurbishing calandria vessels in nuclear reactors, and more specifically, to a method of fastening calandria tubes to the calandria tubesheet plate when refurbishing a nuclear reactor.

BACKGROUND OF THE INVENTION

[0002] Referring to **Figures 1 and 2**, one of the major components of a nuclear reactor is a calandria - a large, sealed tank, in which the nuclear reaction takes place. The calandria is penetrated by many tubes (i.e. calandria tubes) allowing uranium or similar fuel bundles to be inserted into the calandria via fuel channels, and allowing pressure tubes to draw heat to feed the generation system. In a CANDU reactor a fuel channel consists of a 104 mm diameter, 4.3 mm thick Zirconium alloy pressure tube, inserted into a calandria tube of a slightly larger diameter, with two stainless steel end fittings at the ends of the fuel channel. Several hundred calandria tubes, 6.3 m long, are horizontally mounted in the calandria. Garter Spring spacers separate the calandria tubes and pressure tubes. The annular gap between the pressure tubes and calandria tubes are filled with CO₂ gas and acts as an insulator between the “hot” pressure tube and the heavy water moderator in the calandria vessel. Heavy water flows through the pressure tubes, removing heat from the fuel bundles and transferring it to steam generators, where secondary circuit light water is heated and converted into steam to run a turbine. During reactor operation, pressure tube material is subject to high pressure (up to 11.3 MPa), high temperature (up to 310° C) and very high gamma and neutron radiation fields. The Calandria tubes are subjected to head pressure (from the moderator located in the calandria).

[0003] The calandria tubes penetrate the walls of the calandria through the “tube sheets” or “tubesheet plates” at both ends of the calandria. It is necessary that the seal between the tubesheet plates and the calandria tubes be maintained, to prevent the moderator from leaking into the annulus space between the pressure tube and calandria tube which would

overpower the annulus gas system and diminish the efficiency of the insulating properties of the annulus gap.

[0004] When a CANDU reactor is initially fabricated, each hole (or bore) in the tubesheet plate through which the calandria tubes are fed, is machined with grooves as shown in **Figure 3**. With the use of an insert, the calandria tubes are “rolled” with a die or mandrel, to expand the end of the calandria tubes into the grooves in the tubesheet plate as shown in **Figures 4 and 5**. While this provides an effective joint during initial fabrication, it is very difficult to refurbish such joints. Periodically, there is a need to refurbish the calandria and other components of the nuclear reactor, to ensure its safe and efficient operation.

[0005] During retubing of CANDU nuclear reactors the pressure tubes, calandria tube rolled inserts, and the calandria tubes are removed and replaced with new components, however, the existing calandria vessel remains. The two original tubesheet plates that contained the calandria tube rolled joints are re-used. Replacement calandria tube rolled joints are fabricated into the original tubesheet plate bores. These bores undergo unavoidable damage during the calandria tube rolling and removal process, including deformity due to rolling stresses and axial scratches from the removal of the calandria tube. This tubesheet bore damage has been problematic for producing an acceptable replacement calandria tube rolled joint. The joint must be leak-tight, with an acceptably low Helium leak rate through the joint (both transient and steady state), and acceptably strong calandria tube pull out strength. As shown in **Figure 6**, there are two primary paths for leakage.

[0006] While the tubesheet bores could be “re-dressed”, it is very challenging and time consuming to insert a re-dressing tool into the bore, to polish the bore. This is in part because the nuclear reactor had been used and is therefore radioactive, so all operations must be done remotely. Re-dressing will also produce radioactive debris from the surface of the tubesheet bore which must be collected and disposed of.

[0007] There is therefore a need for an improved method of fastening calandria tubes to a tubesheet in a calandria when refurbishing a nuclear reactor.

SUMMARY OF THE INVENTION

[0008] It is an object of the invention to provide an improved method of fastening calandria tubes to a tubesheet in a calandria when refurbishing a nuclear reactor.

[0009] Presently, there is no sure method for providing a leak tight, re-rolled joint. During re-rolling, the bore of the tubesheet plate may be superficially cleaned, or an attempt may be made to re-dress the bore, but neither perform as well as the original joints and in some cases fail to meet the acceptance criteria.

[0010] According to an aspect of the present invention there is provided a method of refurbishing a calandria comprising the steps of: forming circumferential cuts/serrations on the outside diameter of a calandria tube; and expanding/deforming the calandria tube into a bore of a tubesheet plate of the calandria, whereby the sharp edges of the serrations “bite” into the tubesheet plate.

[0011] Other systems, methods, features and advantages of the invention will be, or will become, apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features and advantages be included within this description, be within the scope of the invention, and be protected by the following claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] These and other features of the invention will become more apparent from the following description in which reference is made to the appended drawings wherein:

Figure 1 presents a schematic diagram of a nuclear reactor as known in the art;

Figure 2 presents a simplified diagram of a calandria and immediately related components as known in the art;

Figure 3 presents details of the interface between a grooved tubesheet plate and a calandria tube as known in the art, prior to rolling;

Figures 4, 5 and 6 present details of the interface between a grooved tubesheet plate and a calandria tube as known in the art, following rolling;

Figures 7 and 8 present details of the interface between a used tubesheet plate and a new serrated calandria tube in an embodiment of the invention; and

Figures 9 and 10 present details of the serrations that may be made to a calandria tube in an embodiment of the invention.

DETAILED DESCRIPTION

[0013] One or more currently preferred embodiments have been described by way of example. It will be apparent to persons skilled in the art that a number of variations and modifications can be made without departing from the scope of the invention as defined in the claims.

[0014] An acceptable replacement calandria tube joint can be made by purposefully machining circumferential serrated grooves in the leading edge, outside diameter of the calandria tube. These serrated grooves with sharp edges will “bite” into the tubesheet plate during rolling and effectively make a new metal-to-metal seal between the new calandria tube and the used tubesheet plate. Currently, the outer surface of calandria tubes are smooth. The use of serrated outer surfaces creates multiple knife edges on the outside diameter of the calandria tube which, when mechanically rolled “bite” into the tubesheet material, thereby creating a leak-tight and strong joint. In the CANDU system the calandria tubes are a Zirconium alloy, which is harder than the irradiated 304L stainless steel tubesheet bore, hence the calandria tubes will cut into the tubesheet bores. A number of these grooves in series (3 to 5 for example) will provide numerous seals, providing a very tight replacement calandria tube joint seal.

[0015] As noted above, CANDU reactors are typically fabricated with grooves in the tubesheet bores, and the calandria tubes are rolled into the tubesheet bores. However, when re-tubing the reactor, the tubesheet grooves become damaged and therefore cannot typically produce a good, leak-tight joint. It is not effective to re-dress the bores because of the technical challenges of working remotely, the time required and the creation of radioactive debris from the surface of the tubesheet bore which must be dealt with. In contrast, the system of the invention uses new calandria tubes which (of course) are not radioactive, so the grooves or serrations can be cut into the new calandria tubes in a normal workshop environment, outside the nuclear vault. Thus, there is no radiation issue to the workers, the aforementioned bore re-dressing is not required, and there is no radioactive debris produced.

[0016] With the system of the invention there is less need for dressing or cleaning of the tubesheet bore, and less need for inspection of the used tubesheet bore prior to re-rolling. The leak tightness of the serrated calandria tube is less affected by minor flaws in the tubesheet bore, which are caused during the calandria tube removal process. As well, there is less need for re-release and re-roll of leaky joints with the system of the invention, which otherwise results in a waste of calandria tubing and insert material. Test results have shown that the system of the invention is better than the original roll; results exceed the original new-build pass criteria even after 6 hours steady-state. The design appears to be impervious to axial scratches within the TS bore, and re-design of the insert is not required.

[0017] In the preferred embodiment of the invention, the properties of the calandria materials are as follows. Of course, the materials could change dramatically from one reactor design to the next:

- i) the tubesheet plate is 304L stainless steel, (rolled in section is 1.5" long),
- ii) the calandria tube is a Zirconium alloy, and
- iii) the rolled insert is 410 stainless steel.

The rolled insert has a lower yield strength than the tubesheet plate; thus, the rolled insert plastically yields before the 304 SS yields, providing a resistive force against the

springback of the tubesheet plate and forming a tight seal. Also, the calandria tube is the hardest component of the three, providing the hardness needed to bite into the tubesheet plate.

[0018] Trials were performed using 4 grooves with 90 degree angles on calandria tubes. These trials provided good results, providing re-rolled joints in tubesheet plates that were damaged during the insert/calandria tube removal process with Helium leak rates better than the minimum "New Build" requirements (original pass criteria for new builds was 2E-5 cc/sec Helium leak rate, or better, @ 15 minutes). The test data are presented in **Table 1**. The location of the grooves were as shown in **Figures 7 through 10**. Note the tubesheet bores were used as-is, with no cleaning.

[0019] Other positive results were obtained with the cutting / serrating of the calandria tubes using a single point cutter on a lathe to produce the serrations, at an angle of 90 degrees. The details of the depth, spacing, and # of grooves can be as shown in Figure 8.

[0020] The serrations, grooves, edges and cuts in the calandria tubes may be prepared in various ways, using various cutting and deforming tools including lathes, rollers and dedicated hand tools. As well, the depth, spacing, angle and number of serrations required will change from one implementation of the invention to the next. These parameters will depend on the nature of the materials and the degree of seal / mechanical pullout strength required.

OPTIONS AND ALTERNATIVES

[0021] Additional options include the following:

- 1) rather than rolling, other expansion techniques could be used to fix the serrated calandria tubes of the invention, to the tubesheet bores. For example, explosive expansion could be used; and
- 2) different techniques could be used to create the grooves or serrations at the ends of the calandria tubes. While the main concept of the invention is to effect grooves with a

circumferentially continuous sharp edge, some of the advantages of the invention could be obtained, for example, by scoring, notching, pitting or peening the ends of the calandria tubes.

CONCLUSIONS

[0022] The present invention has been described with regard to one or more embodiments. However, it will be apparent to persons skilled in the art that a number of variations and modifications can be made without departing from the scope of the invention as defined in the claims.

[0023] All citations are hereby incorporated by reference.

WHAT IS CLAIMED IS:

1. A method of refurbishing a calandria comprising the steps of:
providing a replacement calandria tube having an external surface;
forming a plurality of circumferential serrations on the external surface of the replacement calandria tube, at an end;
positioning the serrated end of the replacement calandria tube in a bore of a tubesheet plate of the calandria; and
expanding the serrated end of the replacement calandria tube into the bore of the tubesheet plate, wherein the serrations engage the tubesheet plate forming a leak-tight joint seal.
2. The method of claim 1 wherein the replacement calandria tube comprises material that is harder than the tubesheet plate material.
3. The method of claim 1 wherein the number of the circumferential serrations is between 3 and 5.
4. The method of claim 1 wherein the number of the circumferential serrations is 4.
5. The method of any one of claims 1 to 4 wherein the circumferential serrations have projections of an angle of 90 degrees.
6. The method of any one of claims 1 to 5 wherein the circumferential serrations are concentric.
7. The method of claim 1 wherein the tubesheet plate is made of 304L stainless steel.
8. The method of claim 1 wherein the replacement calandria tube is made of Zirconium alloy.

9. The method of any one of claims 1 to 8 wherein the step of forming the circumferential serrations on the external surface of the replacement calandria tube is performed by machining.
10. The method of any one of claims 1 to 9 wherein the step of expanding the replacement calandria tube comprises the step of rolling the replacement calandria tube into the bore of the tubesheet plate of the calandria with an aid of an insert.
11. The method of claim 10 wherein the insert is made of 410 stainless steel.
12. The method of claim 10 wherein the insert has a lower yield strength than the tubesheet plate, the rolled insert plastically yielding before the tubesheet plate.
13. The method of claim 9 wherein the step of machining circumferential serrations is performed with a single point cutter on a lathe.
14. A method of refurbishing a calandria comprising the steps of:
 - providing a replacement calandria tube having an external surface;
 - forming a plurality of circumferential serrations on the external surface of the replacement calandria tube at an end;
 - assembling the serrated end of the replacement calandria tube, and an insert into a bore of a tubesheet plate of the calandria; and
 - rolling the insert and the replacement calandria tube into the tubesheet plate of the calandria, wherein the serrations engage the tubesheet plate forming a leak-tight joint seal.
15. A replacement calandria tube for use in refurbishment of a calandria, the replacement calandria tube comprising a plurality of circumferential serrations formed on an external surface of the replacement calandria tube, at an end, wherein the serrations engage a tubesheet plate of the calandria when the serrated end is expanded in a bore of the tubesheet plate and the engaged serrations form a leak-tight joint seal.

16. The calandria tube of claim 14 wherein the number of the circumferential serrations is between 3 and 5.
17. The calandria tube of claim 14 wherein the number of the circumferential serrations is 4.
18. The calandria tube of any one of claims 14 to 16 wherein the circumferential serrations have projections of an angle of 90 degrees.
19. The calandria tube of any one of claims 14 to 17 wherein the circumferential serrations are concentric.
20. The calandria tube of any one of claims 14 to 18 wherein the replacement calandria tube is made of Zirconium alloy.

Joint Assembly	End	Post Load Cycle		Development tests Standard re-roll with 4 turns iron out	Custom roll 0.030" using serrated CT	Steady State (hooded) Leak Rate			Serrated groove geometry
		Original roll	@ 15 min			@ 3 hrs	@ 6 hrs	@ 8 hrs	
12	A	2.1E-04 2.9E-04 2.6E-04	1.3E-05 5.5E-05 4.4E-05	Re-rolled @ 15 min	1.0E-08	1.4E-05	2.6E-05	not measured	4 at 90 deg
	B				1.06E-09	1.5E-08	1.5E-08	1.6E-08	4 at 90 deg
	A				7.2E-08	7.0E-06	9.8E-06	not measured	4 at 90 deg

TABLE 1

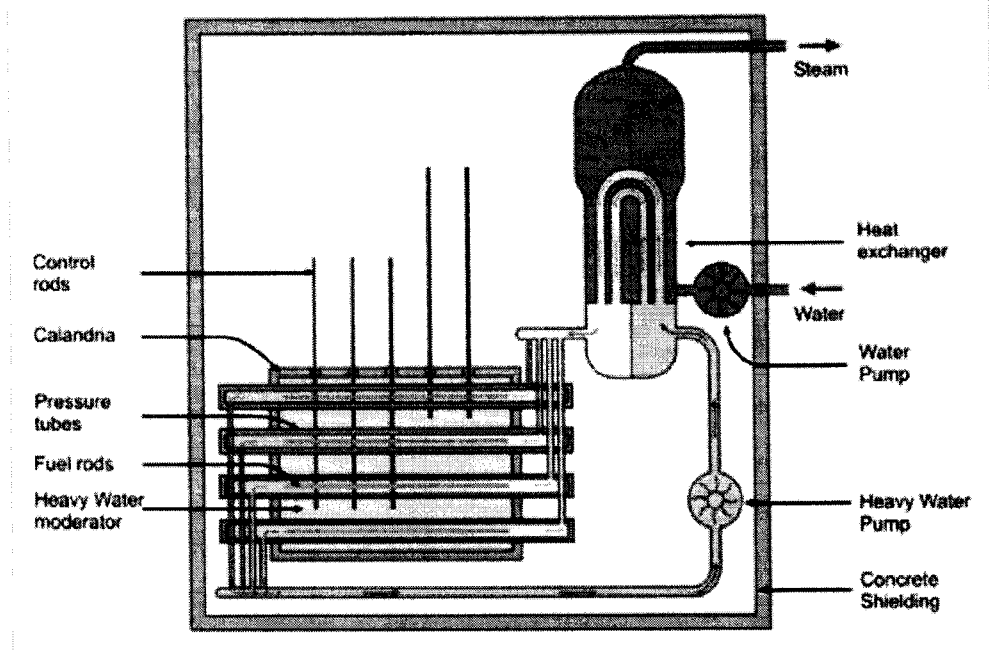


FIGURE 1

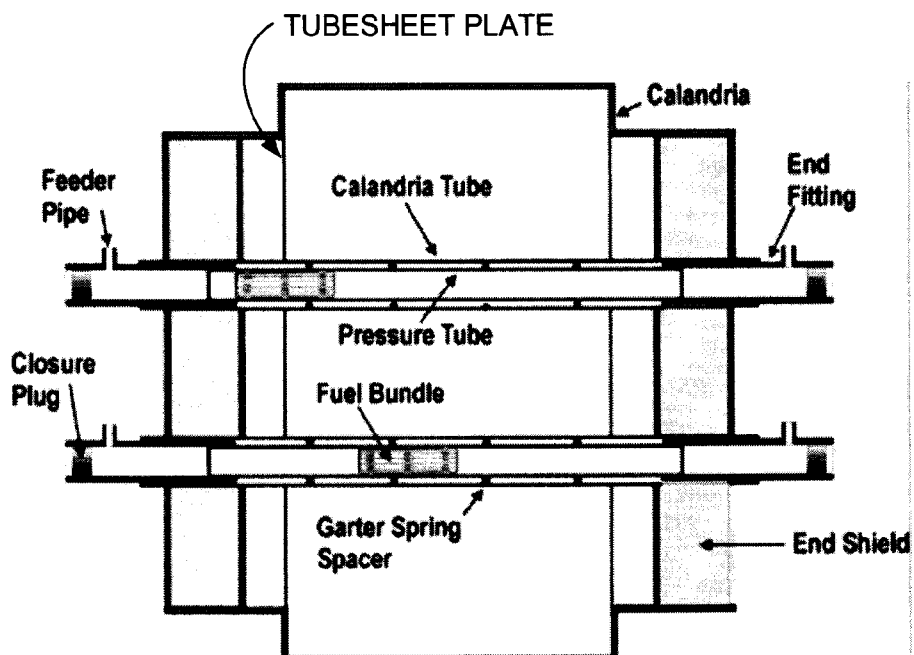


FIGURE 2

FIGURE 3

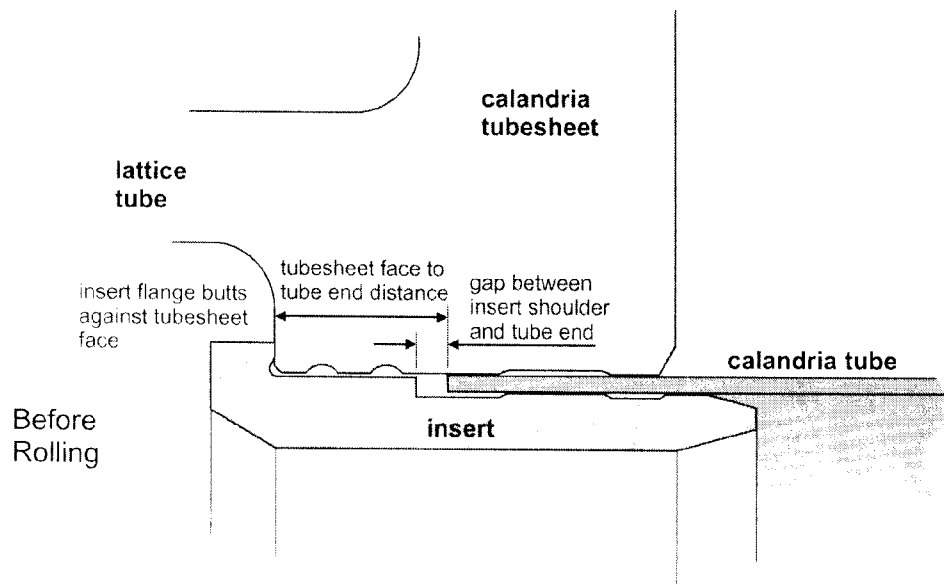
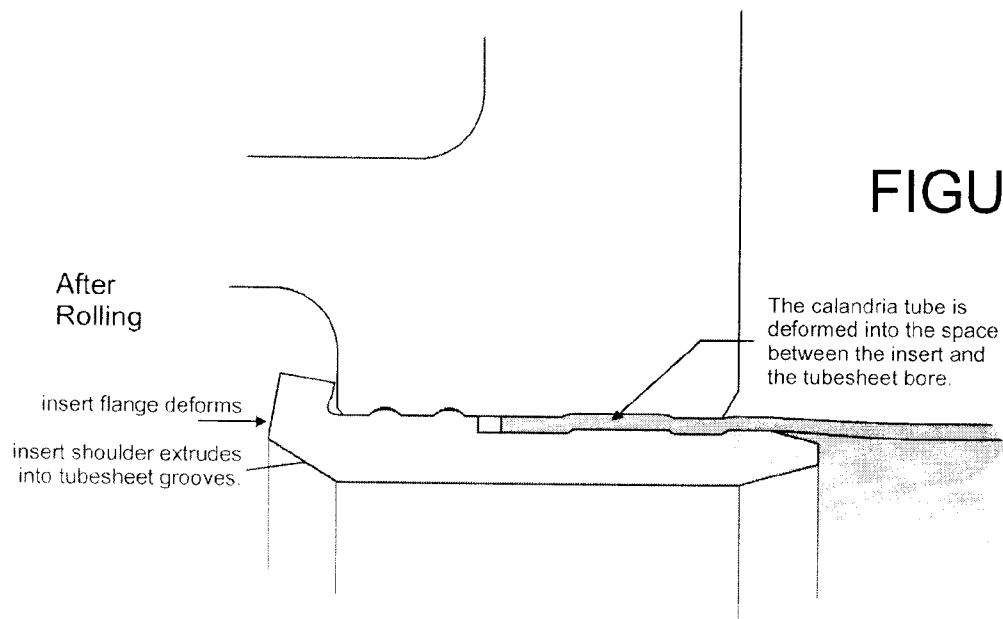


FIGURE 4



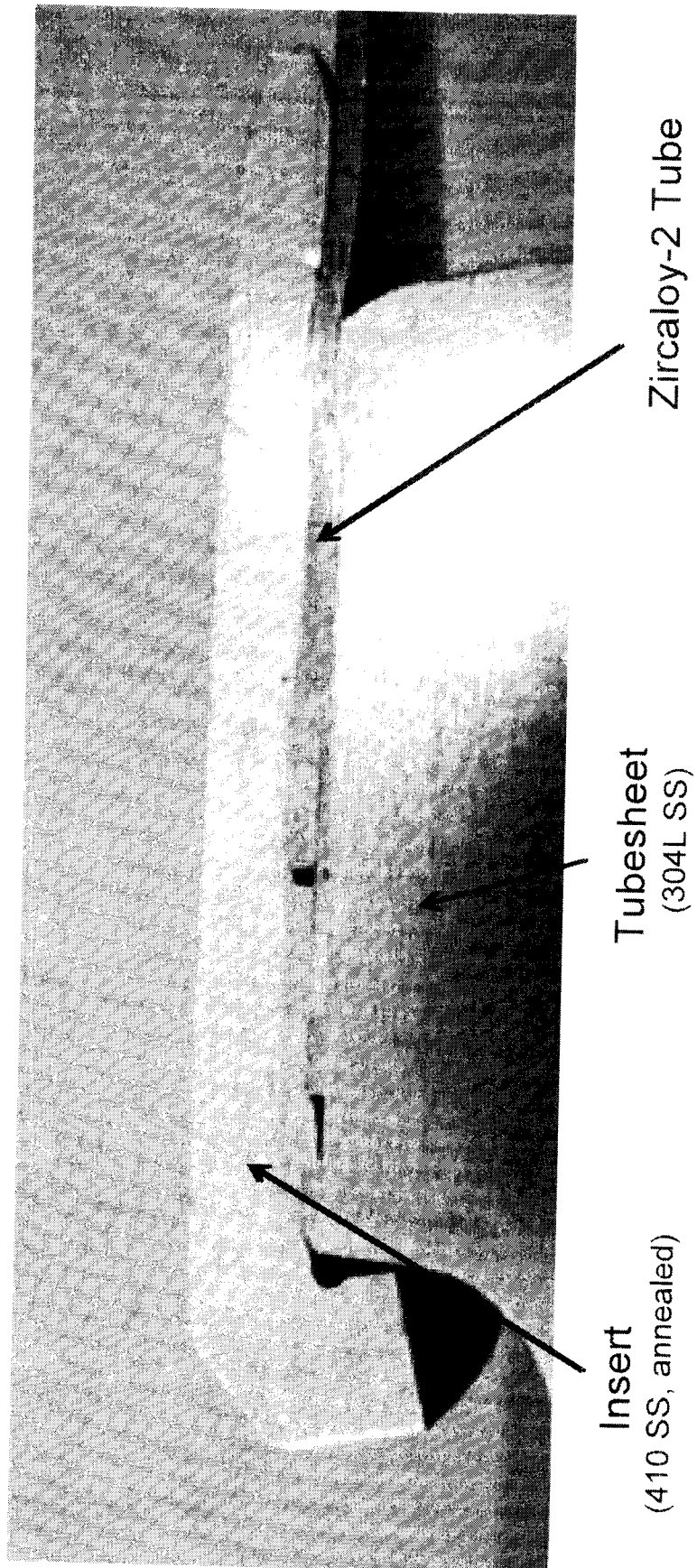
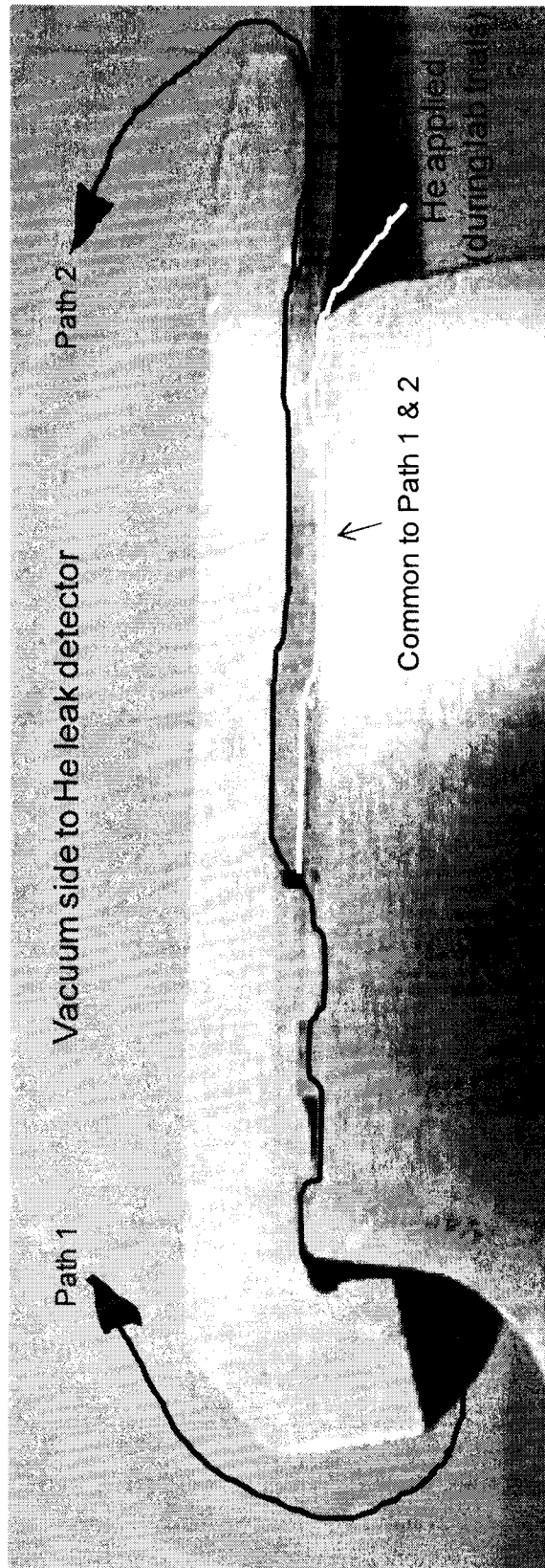
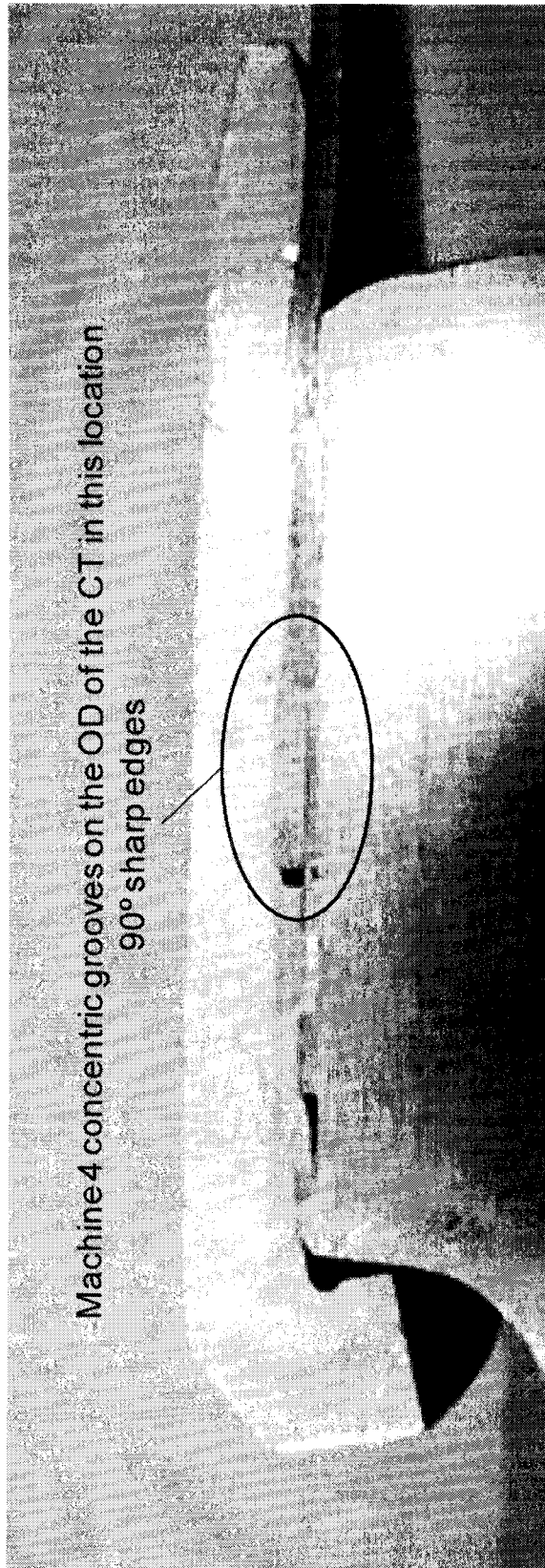


FIGURE 5



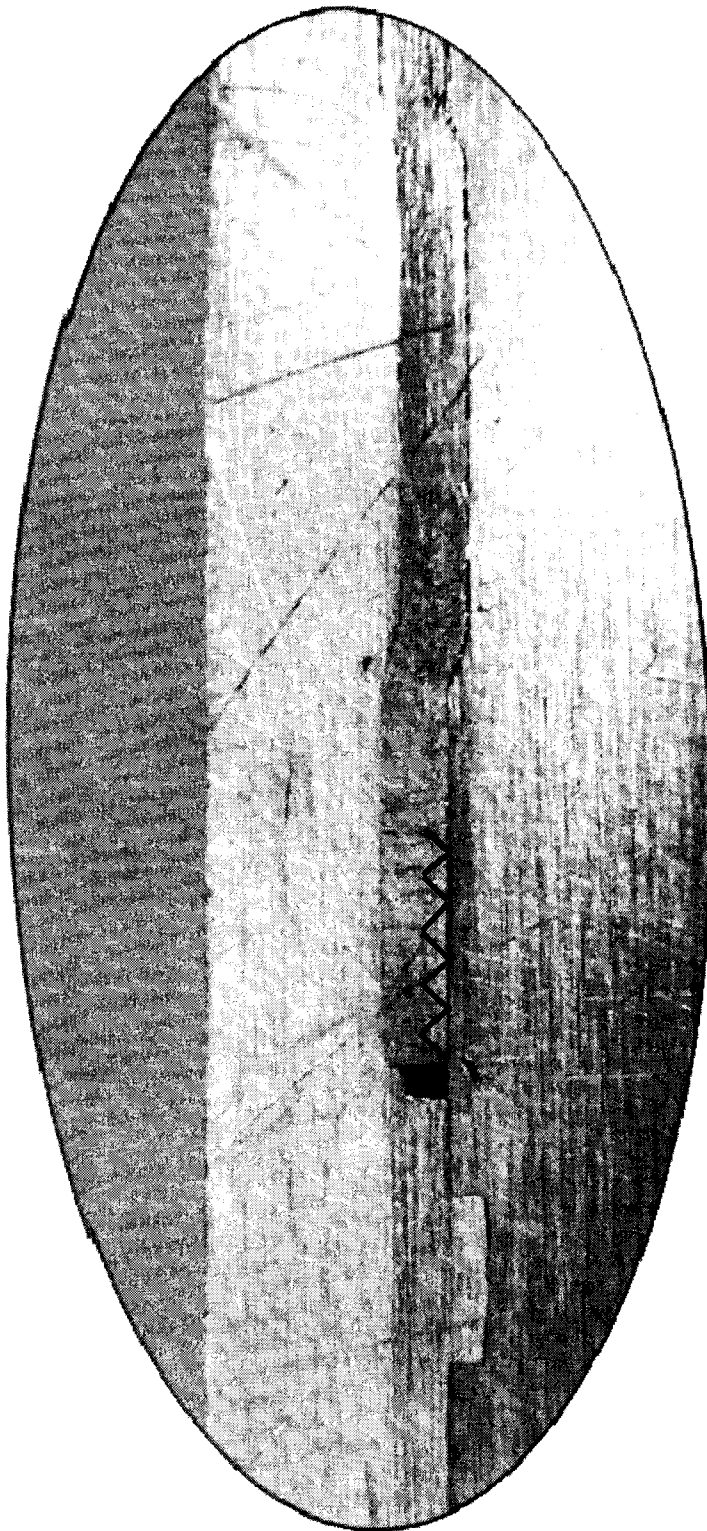
**Two possible leak paths
during Helium leak detection tests**

FIGURE 6



STOP THE LEAK THROUGH THE COMMON LEAK
PATH

FIGURE 7



THE SHARP EDGES ON THE CT "BITE" INTO THE TS MATERIAL DURING
ROLLING AND FORM A LEAK TIGHT SEAL

FIGURE 8

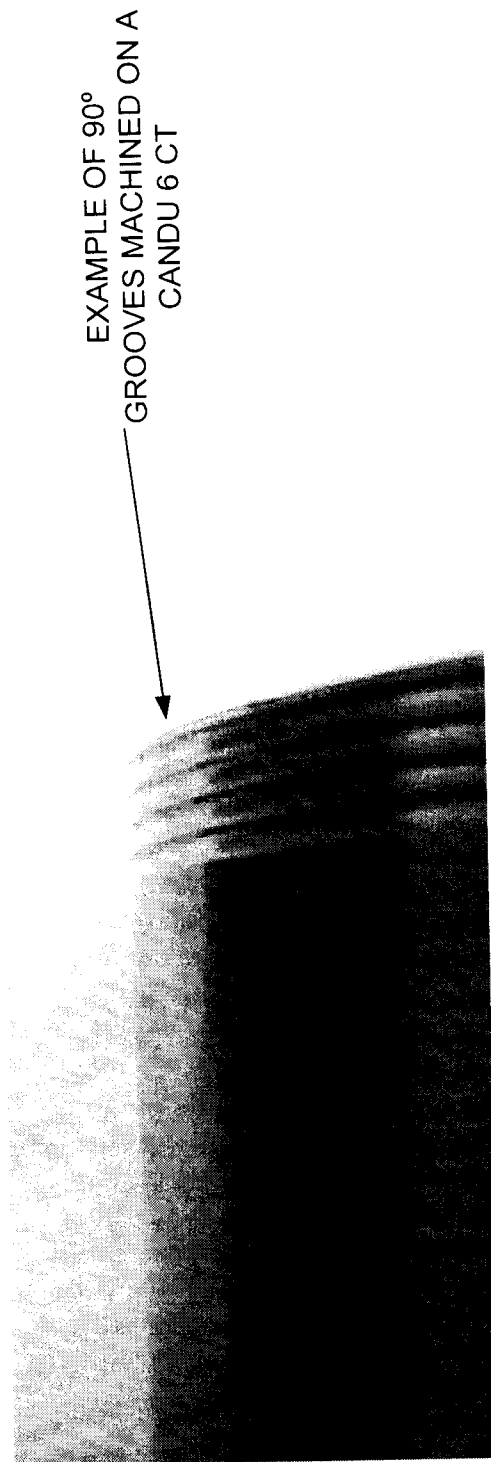
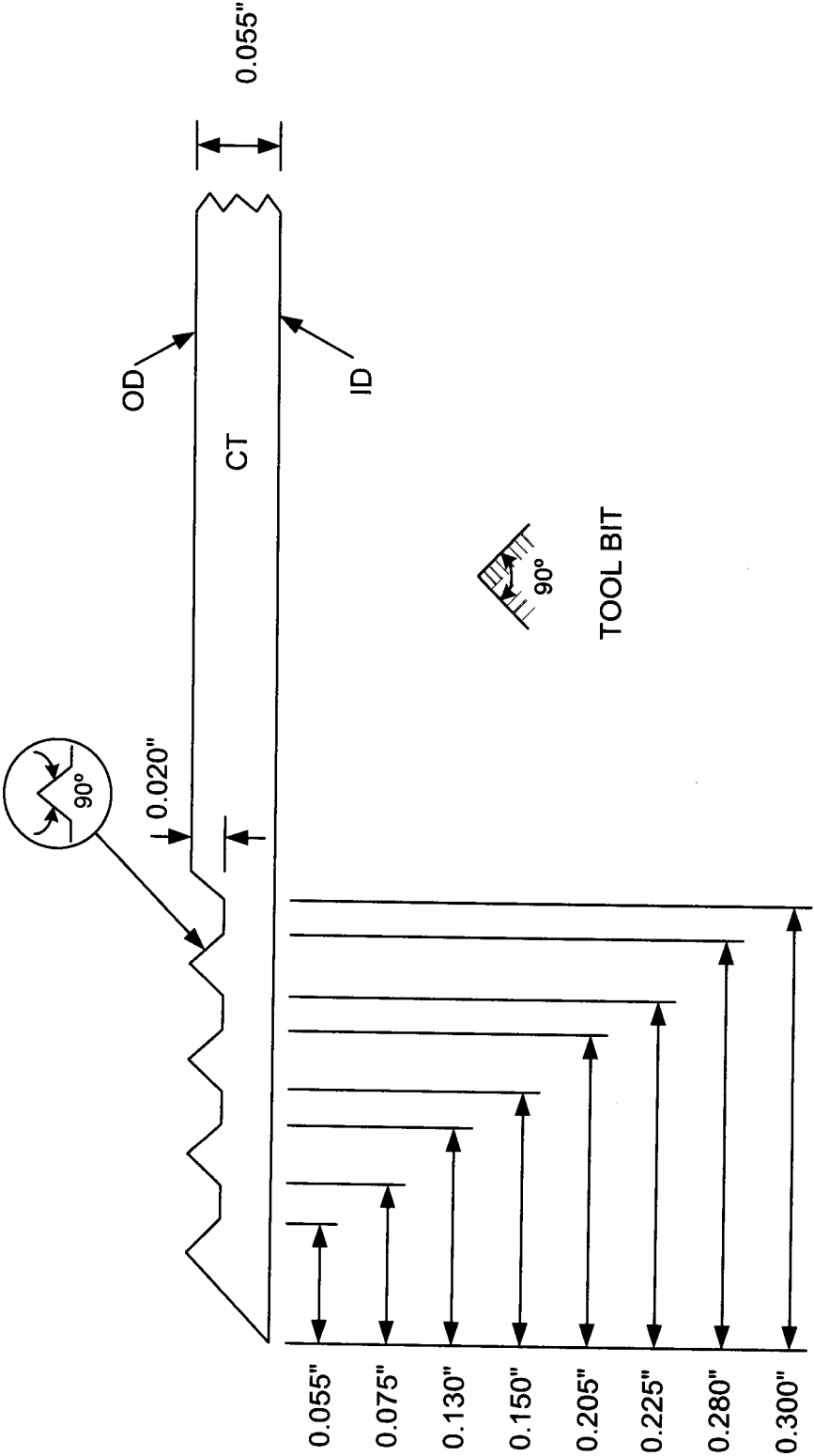


FIGURE 9

FIGURE 10
FOUR CONCENTRIC GROOVES – SERRATED CT



INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2012/000276

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **G21C 17/017** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G21C 17/017 (2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)

Databases: EPOQUE (EPODOC), Canadian Patents Database, Google Patents

Keywords: calandria, tube, joint, replac*, refurbish*, serration, serrated, thread*, leak, CANDU, reactor, rotate, roll

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6,599,067 B2 (Scott et al.) 29 July 2003 (29-07-2003) * Whole Document *	
A	US 3,584,903 (James David Pritchard) 15 June 1971 (15-06-1971) * Whole Document *	
A	US 5,640,434 (Rottenberg) 17 June 1997 (17-06-1997) * Whole Document *	

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

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INTERNATIONAL SEARCH REPORT
Information on patent family members

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Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US6599067B2	29 July 2003 (29-07-2003)	CA2373985A1 CA2373985C CA2686595A1 US2002133928A1	26 September 2002 (26-09-2002) 17 May 2011 (17-05-2011) 26 September 2002 (26-09-2002) 26 September 2002 (26-09-2002)
US3584903A	15 June 1971 (15-06-1971)	DE1911029A1 DE1911029B2 FR2007158A1 GB1218514A	20 November 1969 (20-11-1969) 24 June 1971 (24-06-1971) 02 January 1970 (02-01-1970) 06 January 1971 (06-01-1971)
US5640434A	17 June 1997 (17-06-1997)	None	