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A b s t r a c t :

Initially, the KNK reactor, on account of its compact design, offered but little space for experiments or, in other words, few suitable irradiation positions. Bundle irradiations were possible exclusively on large fuel element assemblies comprising more than 100 pins. Some years ago, when ring-shaped carrier fuel elements were developed which in their center make up an irradiation channel, the possibilities available for experiments were substantially extended. These irradiation channels in the center of ring fuel elements are capable of accommodating both material irradiation rigs and small fuel pin test bundles.

Three variants of ring elements with test bundles will be reported in this paper:
In a first step a ring element was built with a permanently integrated test bundle (19 carbide pins of the Karlsruhe reference concept) while the proven fuel element components have been largely maintained. This irradiation will be completed in autumn 1986 after 380 full power days of operation.

The central topic of this paper will be the technique of reloadable ring elements with replaceable test bundles. A first experiment, TOAST, is in preparation. For this experiment, above all the components of the fuel element head and foot had to be newly developed and tested.
A special version of double-walled replaceable test bundles to be used in the TETRA temperature transient experiments will be briefly mentioned. It is envisaged in these experiments to vary in a defined manner the coolant flow at remotely assembled test bundles consisting of 19 KNK pins each having undergone a high burnup and to use a measuring and control plug placed on the test bundle so that a variety of fuel pin temperature programs can be realized.
Finally, some additional aspects of bundle design will be indicated.

Schnellbrüter-Brennstabbündeltests im KNK II-Reaktor

Z u s a m m e n f a s s u n g :

Der KNK-Reaktor bot ursprünglich wegen seiner Kompaktheit nur wenig Raum für Experimente, bzw. wenig geeignete Bestrahlungspositionen. Bündelbestrahlungen waren nur an großen Brennelementeinheiten mit über 100 Stäben möglich. Mit der Entwicklung ringförmiger Trägerbrennelemente, die in ihrem Zentrum einen Bestrahlungskanal bereitstellen, konnten nun seit einigen Jahren die Experimentiermöglichkeiten beträchtlich erweitert werden. Diese Bestrahlungskanäle im Innern von Ringbrennelementen können sowohl Materialbestrahlungseinsätze als auch kleine Brennstabtestbündel aufnehmen.

In diesem Bericht werden drei Varianten von Ringelementen mit Testbündeln besprochen:
In einem ersten Schritt wurde unter weitgehender Beibehaltung der bewährten Brennelementkomponenten ein Ringelement mit einem fest integrierten Testbündel (19 Karbidstäbe des Karlsruher Referenzkonzeptes) realisiert. Diese Bestrahlung wird nach 380 Vollasttagen im Herbst 1986 abgeschlossen.

Der Schwerpunkt des Berichtes liegt bei der Technik von wiederbeladbaren Ringelementen mit auswechselbaren Testbündeln. Ein erstes Experiment TOAST ist in Vorbereitung. Dafür waren vor allem die Komponenten des Brennelementkopfes und -fußes neu zu entwickeln und zu testen.

Kurz eingegangen wird auf eine Sonderausführung von doppelwandigen auswechselbaren Testbündeln für Temperaturtransientenexperimente TETRA. Bei diesen Experimenten soll an fernbedient assemblierten Testbündeln aus je 19 hochabgebrannten KNK-Stäben in Verbindung mit einem auf die Testbündel aufgesetzten Meß- und Regelstopfen der Kühlmitteldurchsatz definiert verändert werden, wodurch unterschiedlichste Brennstabtemperaturprogramme gefahren werden können.

Abschließend werden noch einige Gesichtspunkte der Bündelauslegung genannt.

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1 Introduction

Initially, the KNK reactor, on account of its compact design, offered but little space for experiments and little suited irradiation positions, respectively. Bundle irradiations were possible only on large fuel element assemblies comprising more than 100 pins. With the development of ring-shaped carrier fuel elements, which in their center make up an irradiation channel, the means of experimentation have been substantially extended since several years. These irradiation channels in the center of ring fuel elements are capable of accomodating both material irradiation rigs and small fuel pin test bundles.

In this report three variants of ring elements with test bundles will be treated.

In a first step a ring element with a permanently integrated 19-pin test bundle was built while keeping largely to the proven fuel element components. In the respective irradiation experiment the Karlsruhe reference concept for carbide with 800 W/cm nominal linear pin power was tested. The irradiation in the core position 201 (Figure 1) will be completed on schedule in autumn 1986 after 380 full power days and 7 % burnup.

The report focuses on the technical aspects of reloadable ring fuel elements with replaceable test bundles. A first experiment, TOAST, to be performed in the core position 205 is being prepared. TOAST is a German acronym for tolerance expansion study. Beginning in 1988 it will be studied on two 19-pin test bundles (with begin of life and end of life conditions BOL and EOL) to which extent a price reducing softening of the previous tolerances applied in oxde fuel pin fabrication can be justified.

A special version of double walled replaceable test bundles for the TETRA temperature transient experiments will be discussed briefly. It is envisaged to perform various cladding tube temperature programs on several remotely assembled test bundles consisting of 19 KNK pins each subjected to high burnups. This will be done in the central core position 100 with a measuring and control plug placed on the test bundle which is capable of varying in a defined manner the coolant flow in the bundle.

Finally, some design aspects will be mentioned.

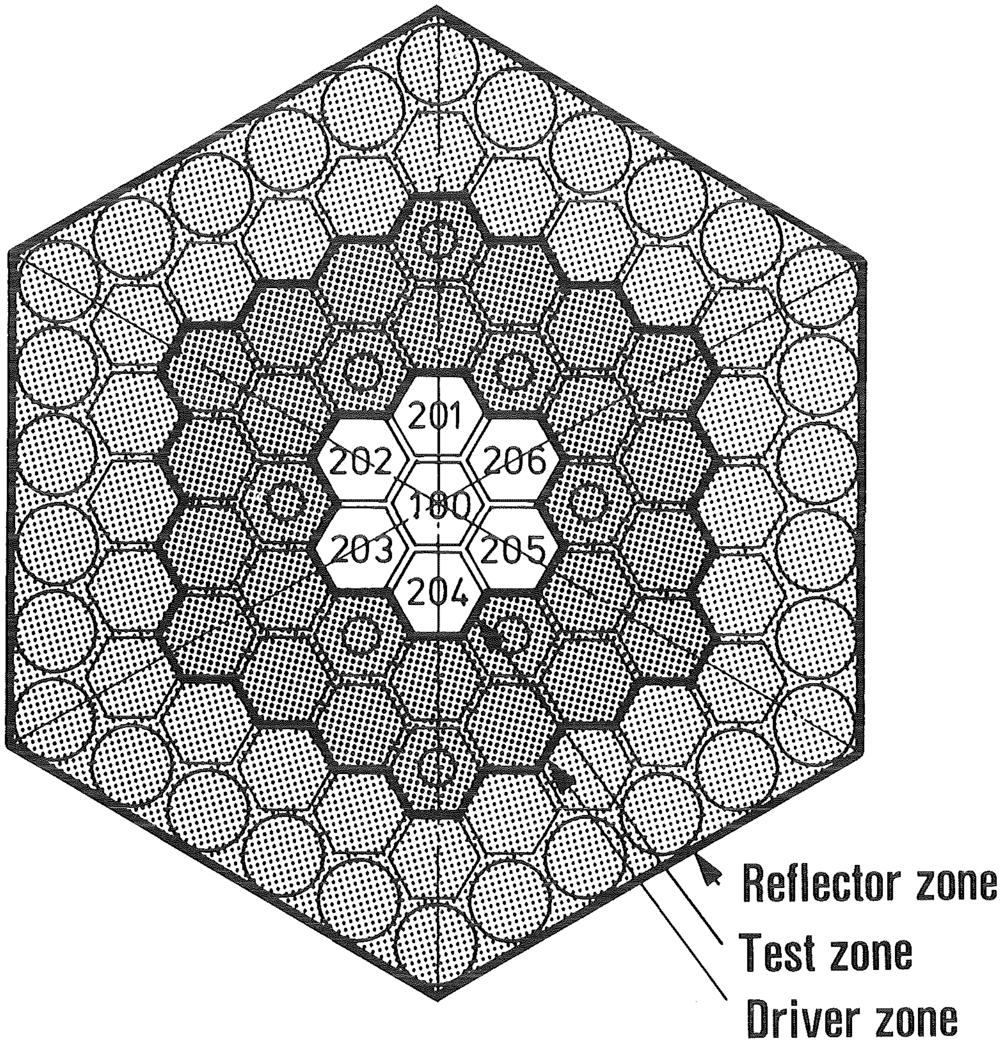

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Fig. 1: KNK II core cross-section.

2 Ring Fuel Element with Permanently Integrated Test Bundle

There were obvious reasons in the first step of development work to keep the proven main components of the standard KNK II fuel elements - the element head with the mixing device, the hexagonal wrapper, and the element foot (Figure 2). This led to the concept of the permanently integrated test bundle which had been realized in the 19-pin carbide bundle.

The carbide bundle is arranged in the interior of an oxide ring element with three rows which contains 102 fuel pins (Figure 3). The bundle zone of about 1600 mm length includes the 600 mm long fuel zone, the upper and lower fertile material zones of 200 mm length each, and fission gas plena at the top and at the bottom.

The 102 fuel pins, 7.6 mm in diameter, of the ring element are clamped at the bottom between a pin holding device and are run eight times through spark eroded spacer grids over their total length. The spacer grids are fixed to six structural pins installed in the corners of the wrapper.

As all the other test zone elements loaded into the reactor, the ring element is hydraulically held down to withstand the sodium flow. For this purpose, a space of reduced pressure is provided below the piston of the element foot in the grid plate insert carrying the fuel elements. Roughly speaking, the holding down force is equivalent to the pressure loss in the fuel element of about 1.3 bar times the surface of the holding down piston. The spaces kept at different pressure levels are sealed by piston rings.

The 19 pins, 8.5 mm diameter, of the test bundle are screwed at the bottom in a pin holding plate which, in turn, is connected with the wrapper via six skirts. The wrapper is attached to the inner wrapper of the ring element via a connecting ring. Also the test fuel pins are run in spacer grids over their total length and the spacer grids are supported in the wrapper through holding pins. A perforated diaphragm at the bundle inlet ensures proper coolant distribution between the test bundle and the ring element.

At the upper end of the bundle the coolant flows out from the various subchannels at different temperatures which is due to load tilting. A mixing device has been placed into the element head in order to attain a stable coolant temperature typical of the element at the temperature measuring point above the inflow pipe. In its standard version the mixing device consists of an angular momentum generating section, the turbulence insert, and the straightener placed behind the inflow pipe, in which the angular momentum declines again. Also the gripping edge is provided in the element head by which the element can be withdrawn with the refueling machine.

Some data on the ring fuel element with the carbide test bundle are given in the following table.

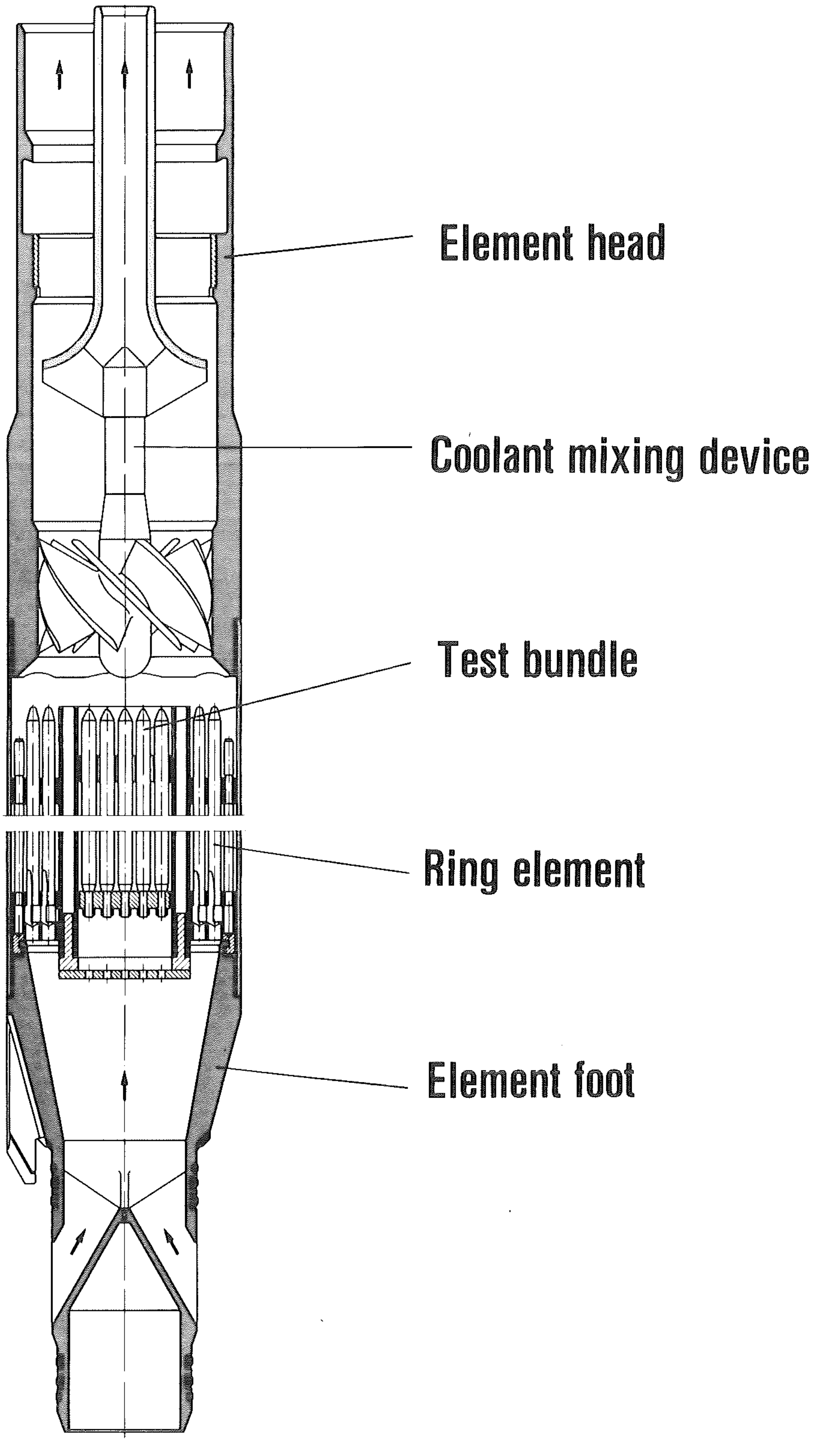

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Fig. 2: KNK ring fuel element with integrated carbide test bundle.

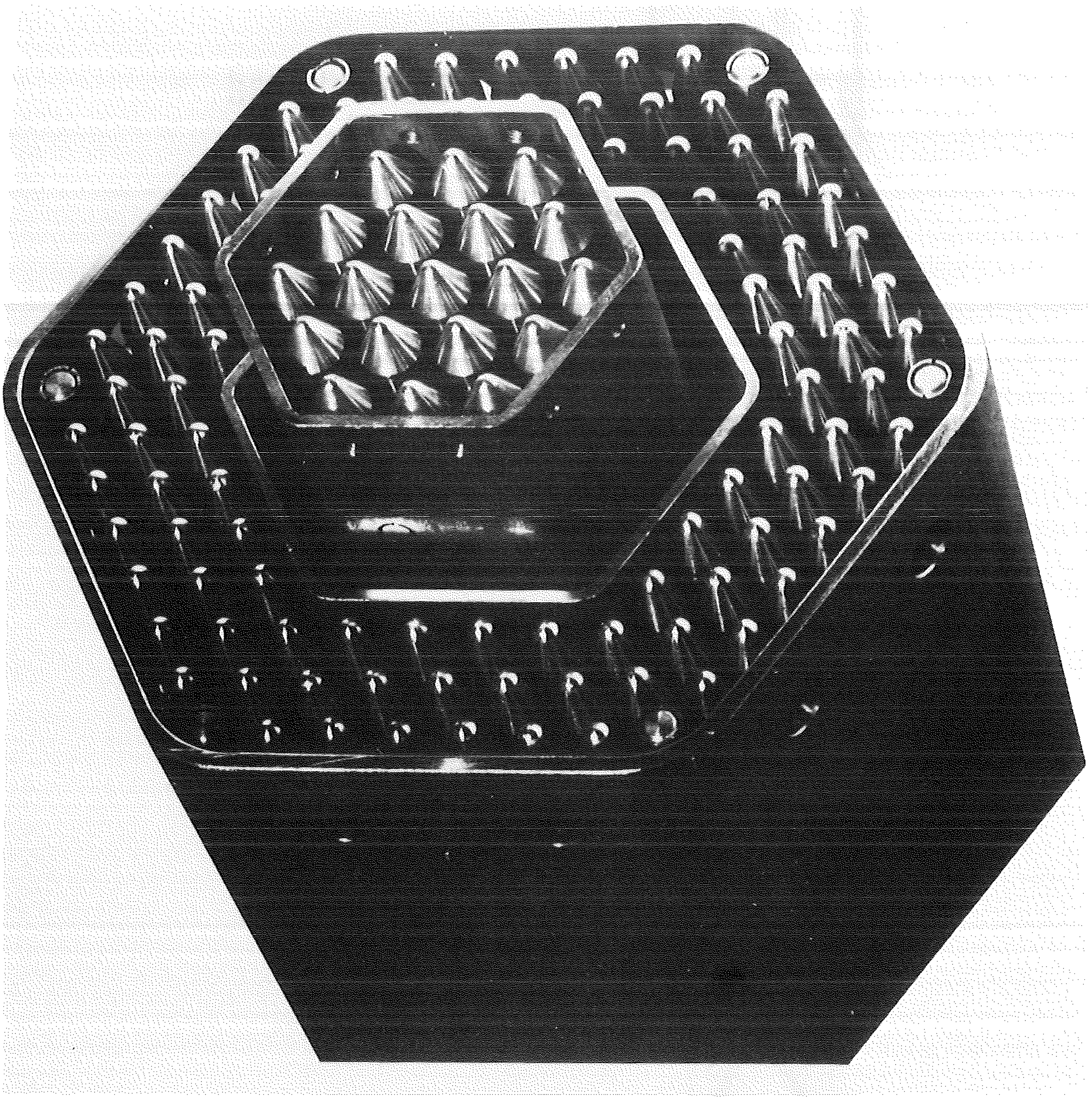

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Fig. 3: KNK II Ring element with a 19-rod mixed carbide test bundle.

		carbide bundle	ring element
fuel		(U, Pu) C	(U, Pu) O_2
smear density %		76	85
pin diameter mm		8.5	7.6
number of pins		19	102
linear pin power W/cm	max. nom.	800	450
	extremal	1000	558
cladding mid wall temperature °C	max. nom.	616	598
element power MW		0.72	1.91
service life FPD		380	380
burn up MWD/kg M	extremal	ca. 85	ca. 67
Na Flow rate kg/s		2.54	7.92
average bundle temperature rise K		211	190

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Design data and operating Conditions of the KNK ring element with carbide test bundle.

3 Reloadable Ring Fuel Elements with Replaceable Test Bundles

Obviously, the concept of the ring element with permanently integrated test bundle is associated with drawbacks. If a fuel pin of the test bundle or ring element suffers from a precocious defect, the irradiation comes to an end and for short-term irradiation the carrier element is at any rate too expensive. By contrast, a reloadable carrier fuel element can be used over years for several test bundle irradiations. However, the concept of replaceability implies some prerequisites which make it necessary to modify the head and foot zones of the element, to test them again, and to provide additional handling devices.

The test bundle and the carrier element must be capable of separate handling which requires, for instance, grabs of different designs, and the test bundle must be secured additionally in the ring element against lift in the flow. In principle, mechanical locks would suffice but they require a high additional handling effort. Therefore, hydraulic holding down was chosen also in this case.

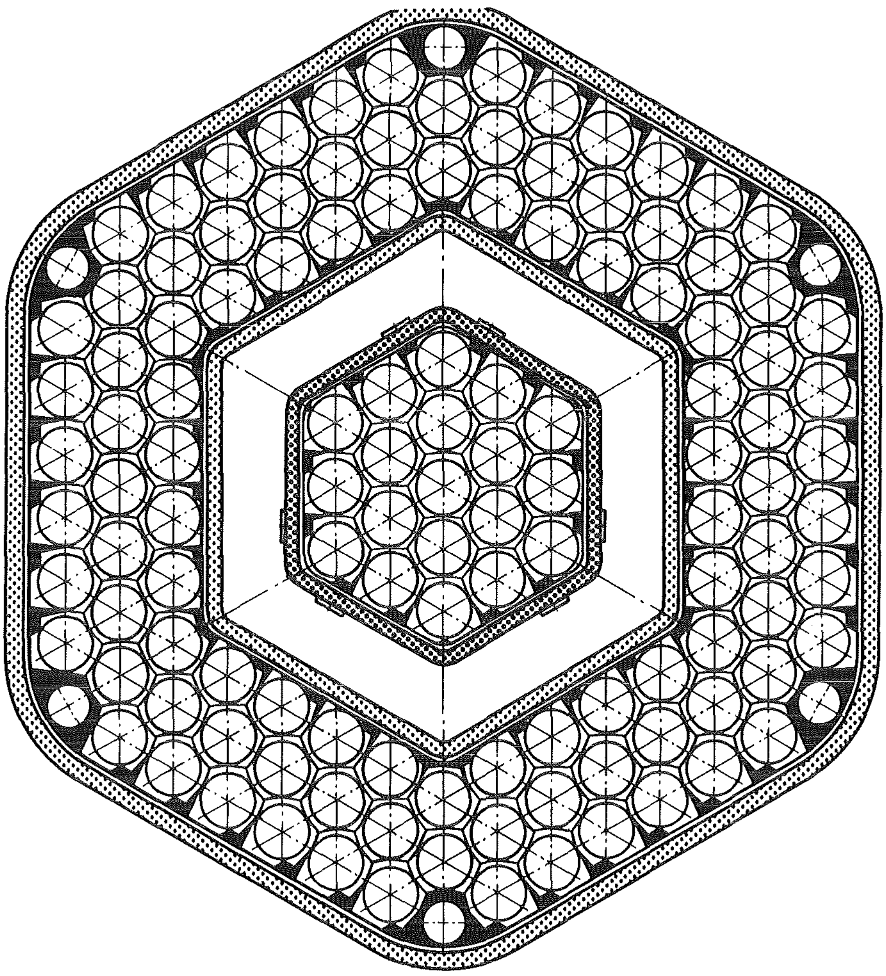
Figure 4 shows a cross-sectional view of the reloadable ring fuel element with the replaceable test bundle. As already mentioned in the introduction, the test bundles are TOAST bundles with oxide fuel, again 19 pins, but in this case with 7.6 mm cladding diameter. Consequently, the width across flats of the wrapper of the test bundle is slighly smaller. The oxide ring element accommodates again three rows with 102 fuel pins of 7.6 mm diameter. The spacers of the ring element are no longer held in a skeleton and fixed to the structural pins but supported by skirts which are point welded to the wrapper. The six rods in the wrapper corners are filling rods.

Figure 5 shows a longitudinal section of the ring element with replaceable test bundles. The hexagonal test bundle is made round in the head and foot zones. The test bundle head consists of the mixing device and an inflow pipe which ends in a mushroom shaped grab hook by which the test bundle can be withdrawn. The head of the test bundle rests on the inner wrapper of the ring element which, in turn, is suspended at the ring element head.

Due to the fact that a holding down pipe is used for replacement of the test bundle and cooling must be provided in the refueling flask, the test bundle head had to be modified in the manner indicated here.

The foot of the test bundle has been given a certain amount of clearance at the lower end of the ring element and by means of a cross shaped carrier device with favorable flow characteristics it is connected with the beaker shaped holding down piston which is open at its bottom end and supplements the ring element foot in hydraulic holding down. One support ring each brings the parts into a central position and one piston ring each seals them against each other. A low sweep flow between the test bundle and the ring element is ensured by the gap provided between them. A guide rib at the ring element foot allows to insert the hexagonal fuel element in the core assembly with an appropriate angular orientation. In the head zone the coolant flows from the ring element into the narrowing down ring gap upwards, is reversed and introduced radially into the mixing chamber through bores. There, strong turbulence effects produce sufficiently good mixing, also with the coolant from the test bundle which arrives at a slower rate. A portion of coolant flows through the inflow pipe to the temperature measuring point above the bundle outlet; most of the flow is discharged in the head of the ring element. A throttling device ensures proper coolant distribution between the ring element and the test bundle; the pressure loss caused by this device will be determined in a test.

A photograph of the shortened TOAST test bundle is shown in Figure 6.



Ring fuel element:

outer width across flats, outer wrapper	122.75 mm
inner width across flats, inner wrapper	62.45 mm
number of fuel pins, Dia. 7.6 mm	102

Test bundle:

outer width across flats of wrapper	44.24 mm
number of fuel pins, Dia. 7.6 mm	19

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Fig. 4: Ring fuel element with TOAST test bundle for KNK.

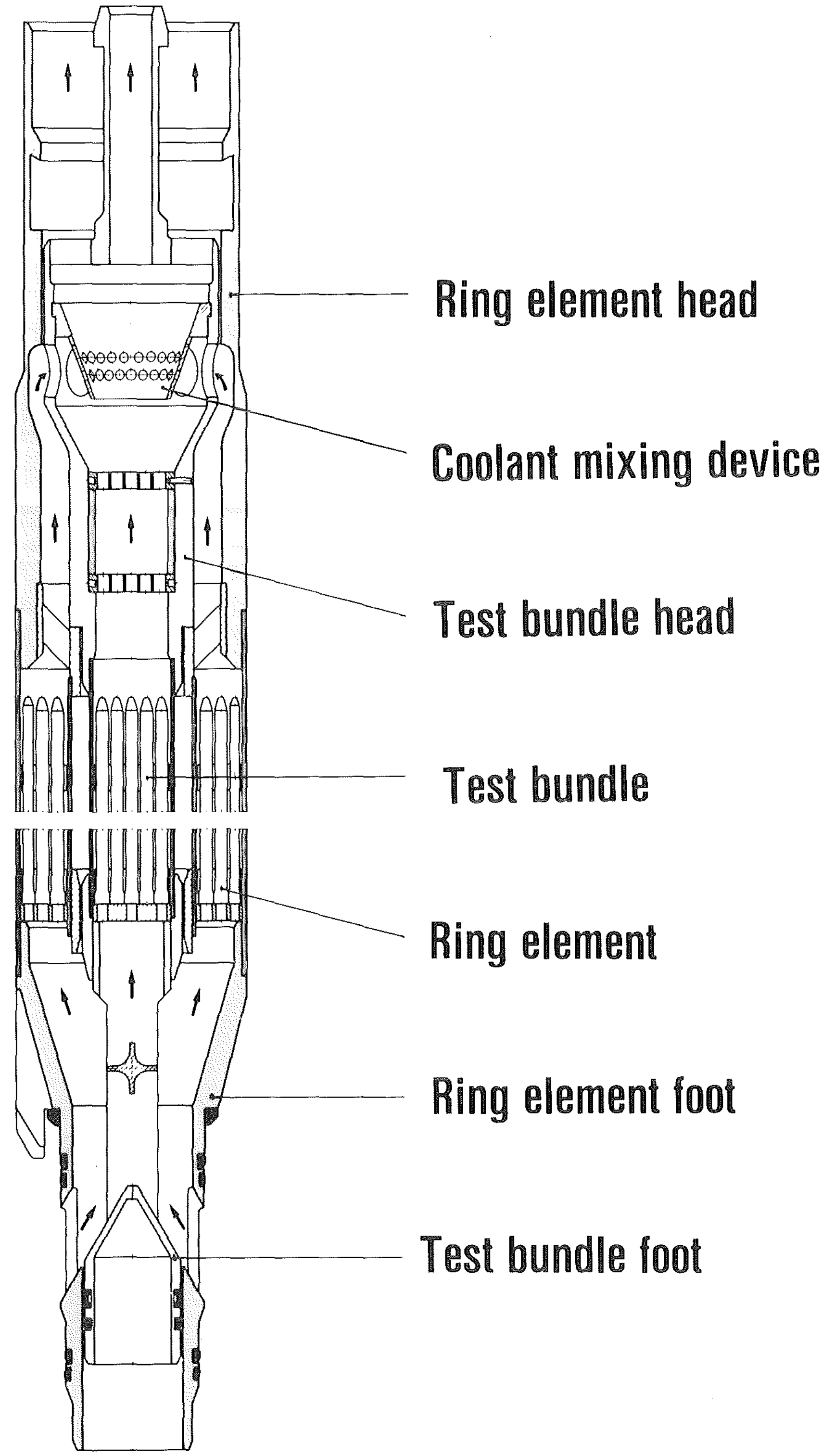

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Fig. 5: Reloadable KNK II ring fuel element with replaceable test bundle.

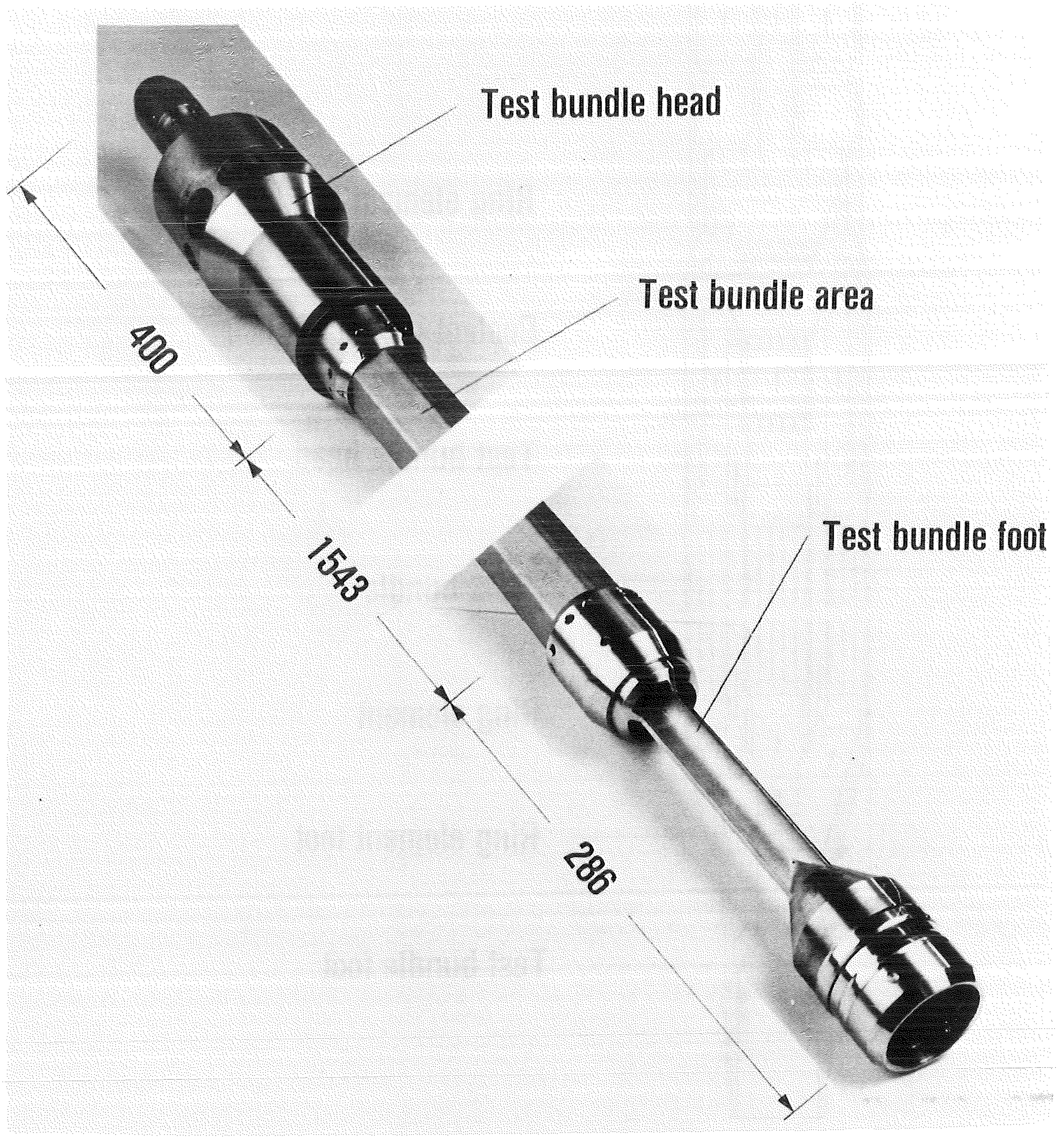

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Fig. 6: TOAST test bundle for KNK.

4 Reloadable Ring Fuel Elements for Temperature Transient Experiments

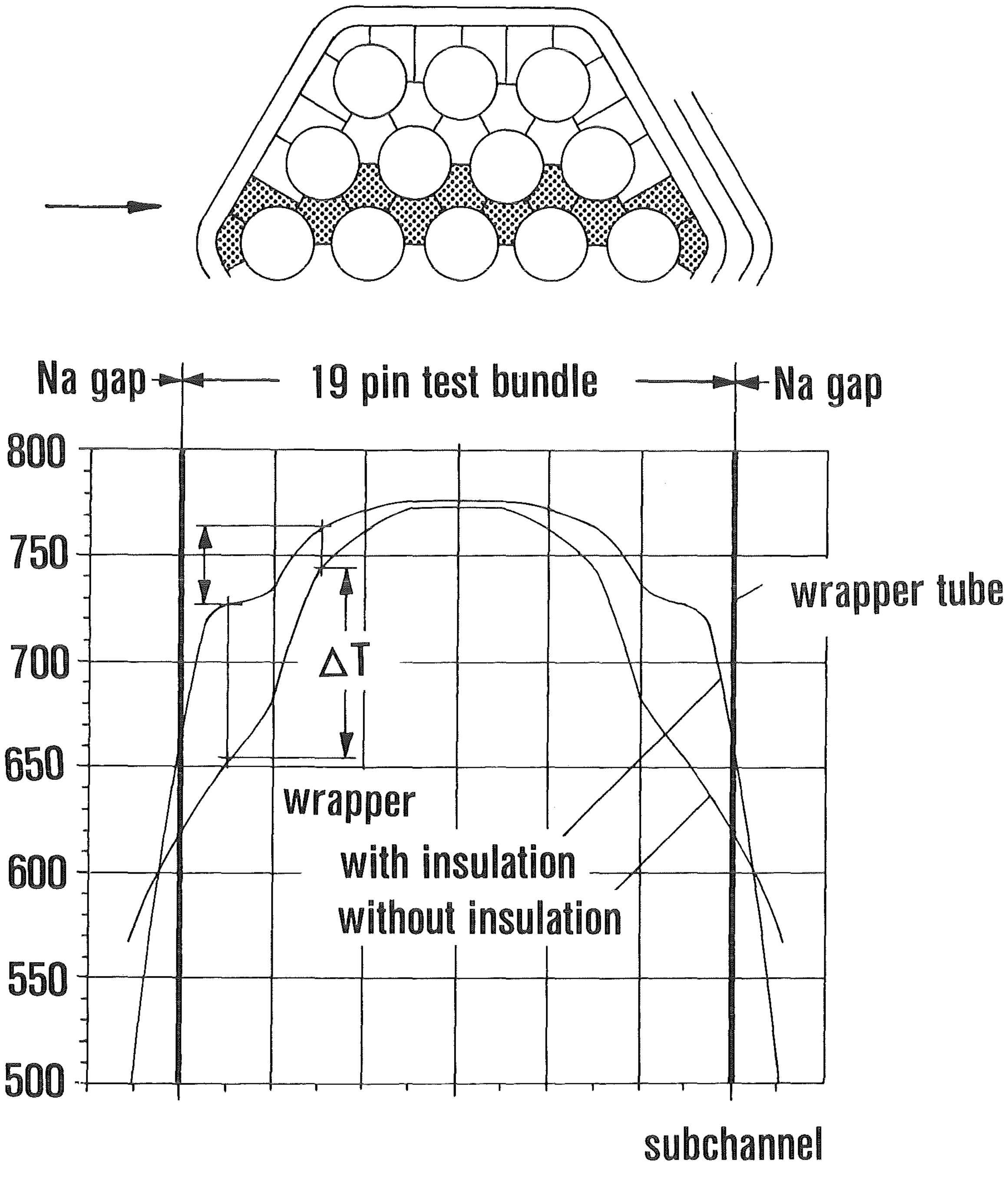
The TETRA temperature transient experiments will be performed to find out the technical design limit for the cladding tube mid-wall temperature. For the time being the mid-wall temperature is limited to 685 °C. It is proposed to carry out experiments involving temperature cycling, but also long-term operation at excessively high temperatures. The maximum cladding tube temperature in the test bundle is to attain up to 800 °C. Consequently, the average sodium outlet temperature will be 750 °C, i.e. about 200 K above that in the ring element. This means that in the outer subchannels of the test bundle the temperature drop will be relatively steep which will lead to high temperature differences on the perimeters of the pins arranged in the outermost row. In order to avoid in these experiments these non-typical cladding stresses and any pin damage that might result from them, the wrapper will be given a double-walled structure. Figure 7 makes clear how the coolant temperature in the outer channels can be raised by the insulating gas gap provided between the two wrapper walls. Insulation of the hot test bundle also offers the advantage that there will be less losses towards the carrier element which will produce a favorable effect on the computational determination of the actual cladding tube temperature on the basis of the energy balance.

Figure 8 shows the cross section of this special element together with the TETRA test bundle. As these experiments can be performed solely in the central reactor position because the required measuring and control plug must be introduced via the penetrations in the reactor lid, the carrier element can occupy only two rows which means that it includes 66 oxide pins.

As one can see in the longitudinal section in Figure 9 also the head zone is double walled for thermal insulation of the test bundle. Hydraulic holding down of the test bundle can be dispensed with because in-pile test operation is possible only with the measuring and control plug placed at the top of the test bundle head. The differences in thermal expansion of the double walled test bundle structure are accomodated by bellows which at the bundle inlet are exposed to a temperature as low as 360 °C.

The coolant mixing device in the head zone is of a design similar to that in the TOAST experiment.

As the test bundles have to be assembled from fuel pins which have experienced high burnups, they are made so as to be suited for remote handling. The individual inspection and assembly steps are being exercised on a dummy installed in the Hot Cells facility.



* at top of the core

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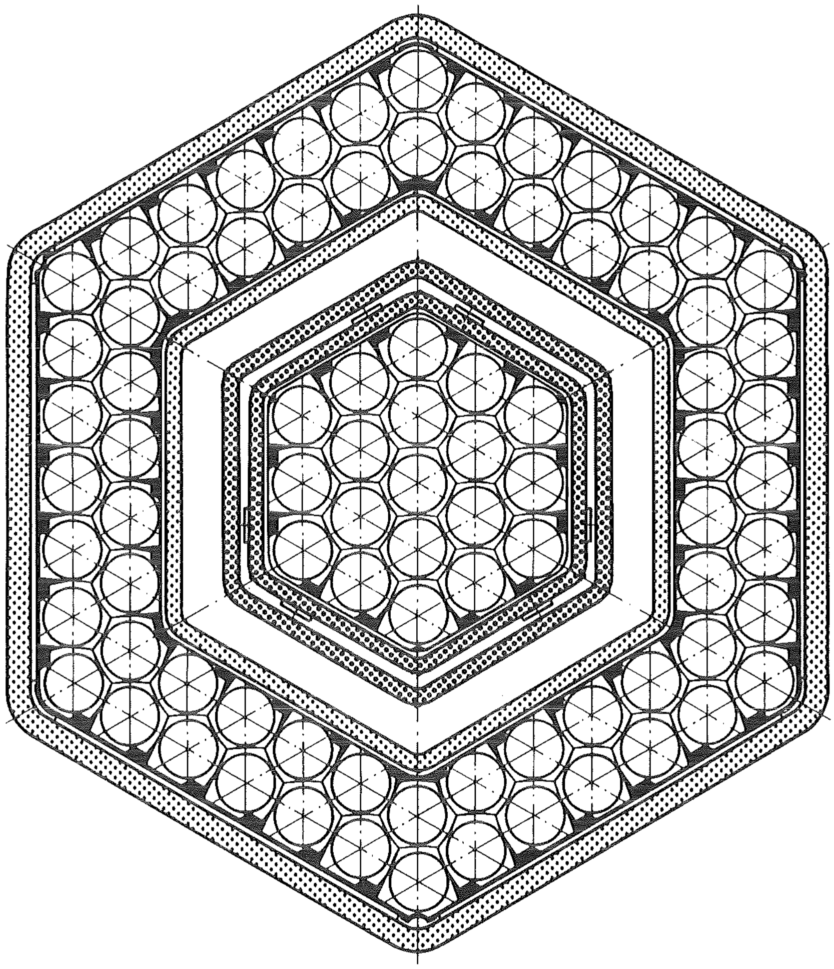
Fig. 7: Radial temperature distribution in the TETRA experiment.



Ring fuel element:

outer width across flats of outer wrapper	108.3 mm
inner width across flats of inner wrapper	62.45 mm
number of fuel pins, Dia. 7.6 mm	66

Test bundle:

outer width across flats of outer wrapper	51.6 mm
number of fuel pins, Dia. 7.6 mm	19

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Fig. 8: Ring fuel element with TETRA test bundle for KNK .

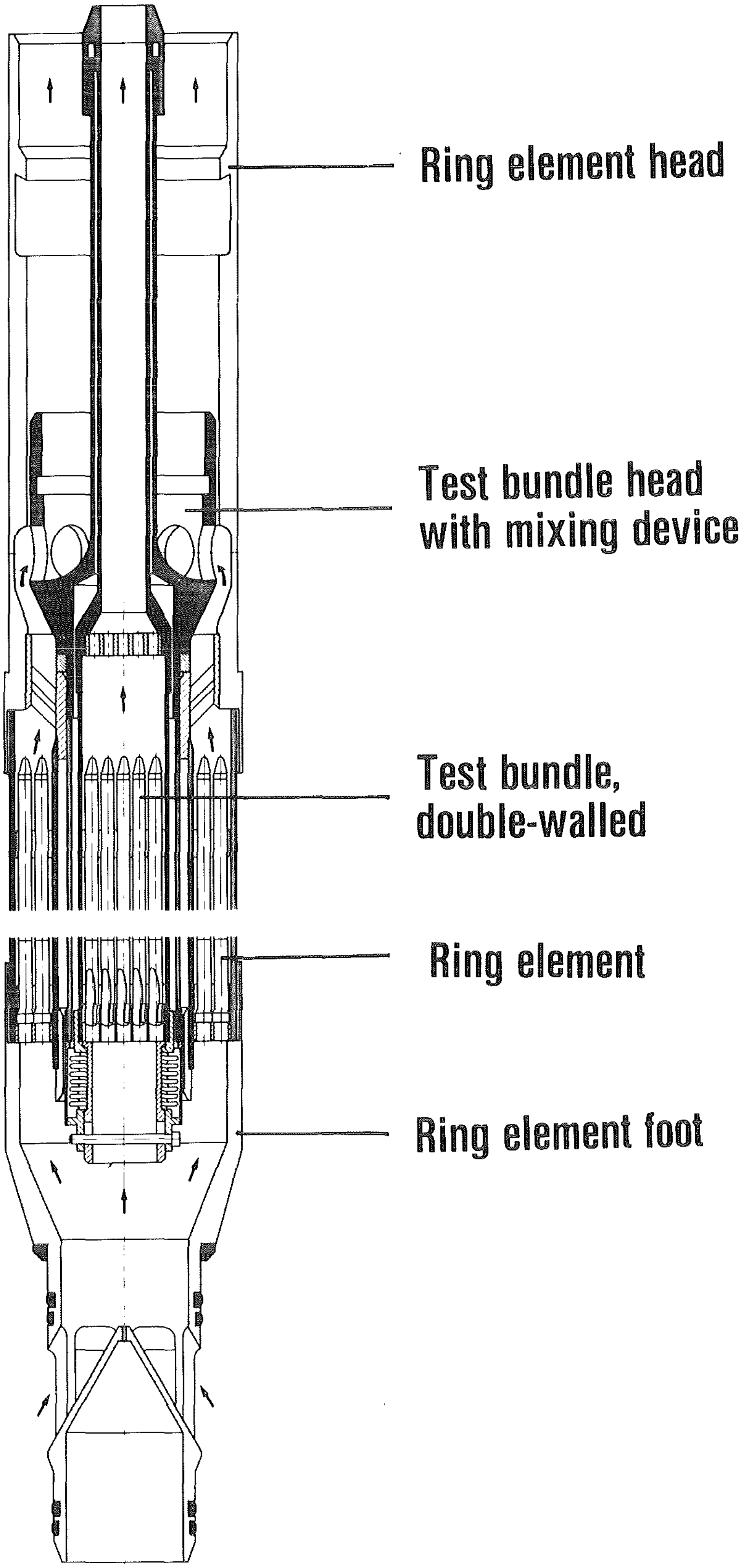

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Fig. 9: Reloadable KNK ring fuel element with TETRA test bundle.

5 Some Aspects of Bundle Design and Authorizations for the Conduct of Experiments

The central topics in the design reports to be submitted for obtaining the authorization to perform bundle experiments include

- fuel pin design,
- thermohydraulic design,
- stress analysis for the spacer grids,and
- calculation of stresses and strains acting in the bundle structures.

Specified design criteria must be met. For instance, regarding the fuel pin it has to be proved that no fuel melting and no cladding tube rupture will occur. To guarantee this, the computational models take into account the temperature distribution, the buildup of fission gas pressure, the stress distribution, and the mechanical interaction of fuel and cladding.

On the basis of balance equations for momentum, mass and energy the distribution of coolant flow, the coolant temperature (Figure 10), and the pressure loss in the bundle are defined for any subchannel in thermohydraulic design. From the coolant temperature we can then calculate

- the temperature distribution over the length and perimeter of the fuel pins with a view to pin design,
- the temperature distribution in the spacer grids with a view to stress analysis,
- the temperature distribution over the length and perimeter of the wrappers with a view to stress and strain evaluation.

The stress analysis code for the spacers calculates by the Finite Element Method the stresses and displacements in grid structures of any degree of complexity. Friction forces resulting from bending and lengthening of the fuel pins are taken into account in the same way as forces generated by inhibition of thermal strain and neutron induced differential volumetric swelling.

The code for the static computation of stresses and strains occuring in a hexagonal wrapper takes into account the pressure and temperature distribution, the gamma heating, forces acting on the supporting planes, thermal creep and irradiation induced creep and swelling.

Major elements for incorporation into the documents to be submitted in order to obtain the authorization for this type of experiments, besides the design reports, are

- drawings and parts lists,
- specifications (fuel pins, wrappers, single parts),
- inspection and welding schedules,
- statistical analyses of the impacts of tolerances and uncertainty factors (hot channel analysis),
- comprehensive safety considerations, and
- tests.

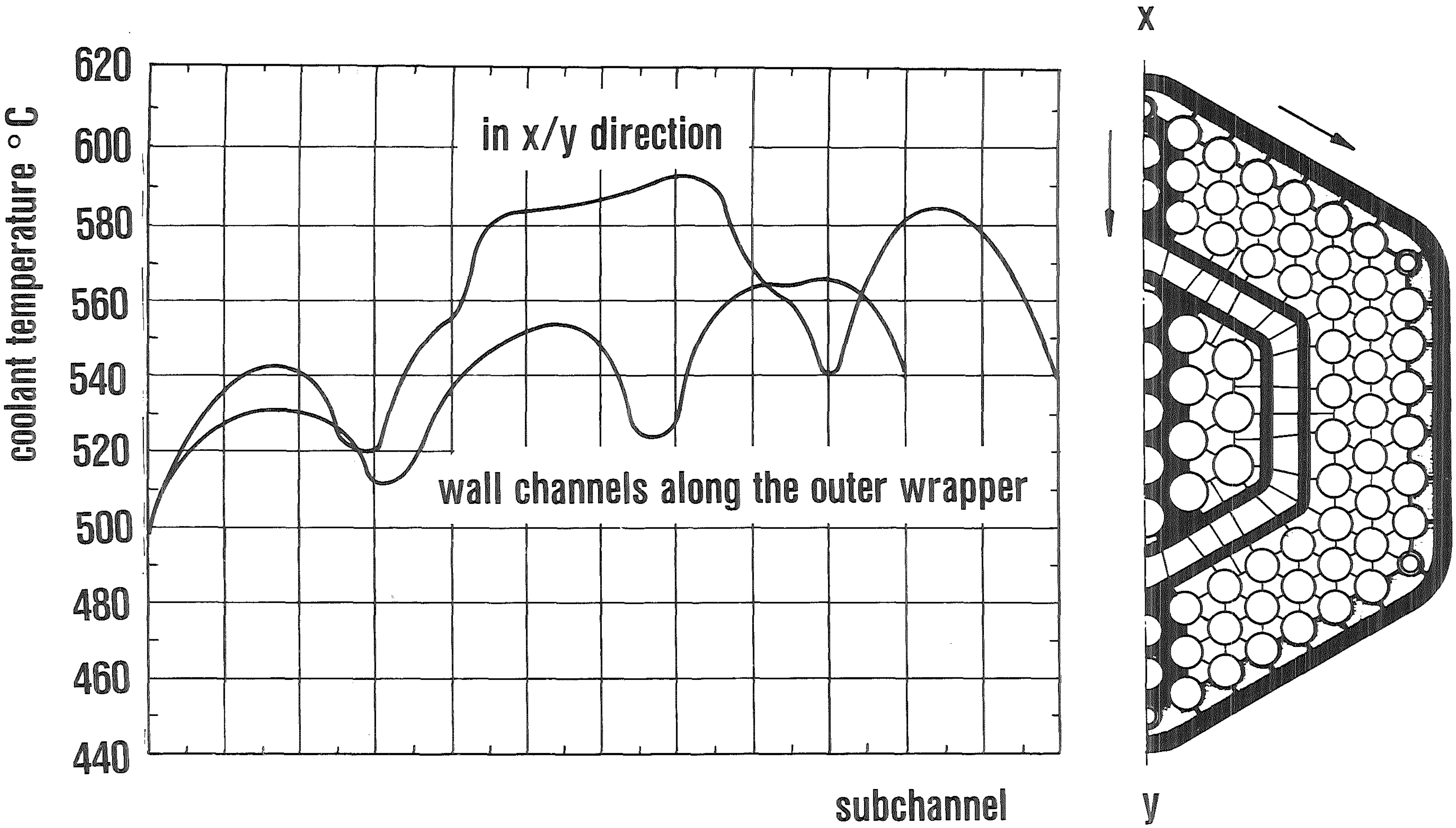

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Fig. 10: Temperature distribution in subchannels (at top of the core and load tilting).