UNIFIED FUEL ELEMENTS DEVELOPMENT FOR RESEARCH REACTORS

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ABSTRACT

Square cross-section rod type fuel elements have been developed for Russian pooltype research reactors. New fuel elements can replace the large nomenclature of tubular fuel elements with round, square and hexahedral cross-sections and to solve a problem of enrichment reduction.
The fuel assembly designs with rod type fuel elements have been developed. The overall dimensions of existing assemblies are preserved in this one.
The experimental-industrial fabricating process of fuel elements, based on a joint extrusion method has been developed. The fabricating process has been tested in laboratory conditions. 150 experimental fuel element samples of the various sizes were produced.

INTRODUCTION

The tubular type fuel elements are used in Russian research reactors, and abroad in reactors, constructed with participation of Russia. Despite the high efficiency of these fuel elements, there are following problems:

- The absence of automatic fabricating process of fuel elements owing to the great variety of the sizes and configurations (about 40 types) results in significant labor intensity of manufacturing;
- The thin-walled design of fuel elements limits a fuel loading, and so considerably complicates a task of fuel enrichment reduction.

The solution of these problems can be simplified if the assemblies with unified rod type fuel elements will be used.

The results of development of design and experimental-industrial fabricating process of rod type fuel elements are submitted in the report. It is shown that the assemblies with rod type fuel elements can be used practically in all pool-type research reactors without any changes in the structure and sizes of the reactor cores. The preliminary technical estimation of rod type fuel elements manufacturing was carried out.

FUEL ELEMENT AND ASSEMBLY DESIGN

The assembly design variants with rod type fuel elements were selected as a result of comparative analysis of the geometrical, hydraulic and thermal characteristics of fuel assemblies with tubular and rod type fuel elements. The results of computational investigations were expounded in paper [1].

Fuel element is a square cross-section rod with four ribs. Fuel element is curled around longitudinal axis with pitch equal H=360 mm (Figure 1). The geometrical characteristics of two optimum- variants of fuel elements are given in Table 1.

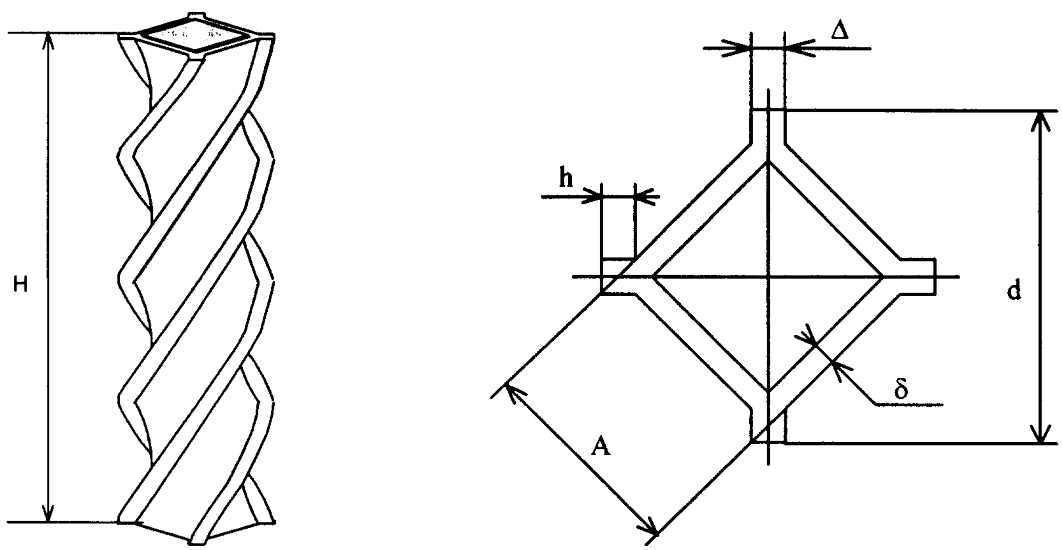

Figure 1. Fuel Element Design

Table 1. Fuel Element Geometrical Characteristics

Circum-scribed Diameter d_c, mm	Rib Width Δ, mm	Rib Height H, mm	Square Side Dimension A, mm	Cladding Thickness δ, mm	Fuel Element Area, mm^2	Fuel Element Perimeter, mm	Fuel Composition Area, mm
4,85	0,4	0,6	2,88	0,3	9,08	15,65	5,19
5,20	0,5	0,75	2,97	0,3	10,07	17,05	5,65

The well-known constructional and fuel materials will be used for fuel elements manufacturing: aluminum alloys, U02 and U3Si2.

At the first stage it is offered to apply fuel assembly with outside cover tube (with shroud). Such assembly design was completely worked up. Two model fuel assemblies of VVR-M and IRT-M types were made.

The fuel bundle is located in a shroud on a supporting grid, forming triangular or square compact packing. The distance between the fuel elements is ensured by means of spiral ribs and special grid

In the top part of a shroud. The form and the overall dimensions of shroud are selected in the correspondence with the concrete sizes of elementary cells of the reactor cores. The sizes and design of end details are retained, that's why it is possible to place rod type assembly in the reactor core together with old type fuel assemblies. All details of assemblies are made of aluminum alloys.

At the second stage it is supposed to use fuel assemblies without outside cover tube. This design is under development. It will make possible to place a fuel bundle directly in an elementary cell of the reactor core.

Fuel elements of two offered sizes allow to group fuel assemblies practically for anyone research reactor without change of existing overall dimensions and configurations of the reactor cores.
The cross-sections of assemblies with rod type fuel elements for various Russian research reactors (IRT-M, VVR-M, VVR-C, IV`V-M, MR) and American MTR type research reactor are schematically shown in Figure 2. The basic geometrical characteristics of these rod assemblies are submitted in Table 2. The comparison of geometrical parameters of the rod, tubular and plate assemblies is carried out with the help of the diagrams, shown in Figure 3.

Table 2. Fuel assembly geometrical characteristics

Fuel Assembly Type	Number of Fuel Elements	Circumscribed Diameter, mm	Cross section Area, mm^2	Heat Transfer Surface, m^2	Hydraulic Diameter, mm	Fuel Area, mm^2	Specific Heat Transfer Surface, 1/cm	Meat Volume Fraction
VVR-M	37	5,2	542,2	0,32	2,92	207,8	5,95	0,433
IRT-M	196	4,85	2980,8	1,78	3,57	1017	6,0	0,389
MR	169	4,85	2454,4	2,64	2,88	866,1	5,97	0,467
VVR-Z	169	5,2	2397,5	1,44	3,07	949,2	6,56	0,426
IVV-M	90	5,2	1382,4	0,77	3,17	505,5	4,33	0,309
MTR	240	4,85	3680,8	2,25	3,78	1230	6,15	0,395

The ratios of geometric characteristics of rod type assemblies to the same characteristics of the other type assemblies are represented on the diagram.
The analysis of the diagrams shows, that practically in all cases we have the following results:

- The fuel area of rod assemblies is increased in 1,5-2 times.
- The specific heat transfer surface of rod type assemblies is increased in 1,3-2 times.
- The metal to water ratio in an elementary cell of the reactor core practically isn't changed; the volume fraction of coolant is decreased insignificantly;
- The hydraulic diameter of rod type assemblies is decreased and, hence, the coolant flow through assembly is reduced. However heat-hydraulic calculations have shown, that it will weakly affect the assembly heat characteristics.

DEVELOPMENT OF EXPERIMENTAL-INDUSTRIAL FABRICATING PROCESS OF FUEL ELEMENTS

The fabricating process of rod fuel elements based on the method of joint extrusion of dispersion meat and cladding. The main rig for rod fuel elements fabricating by this method is the moulding

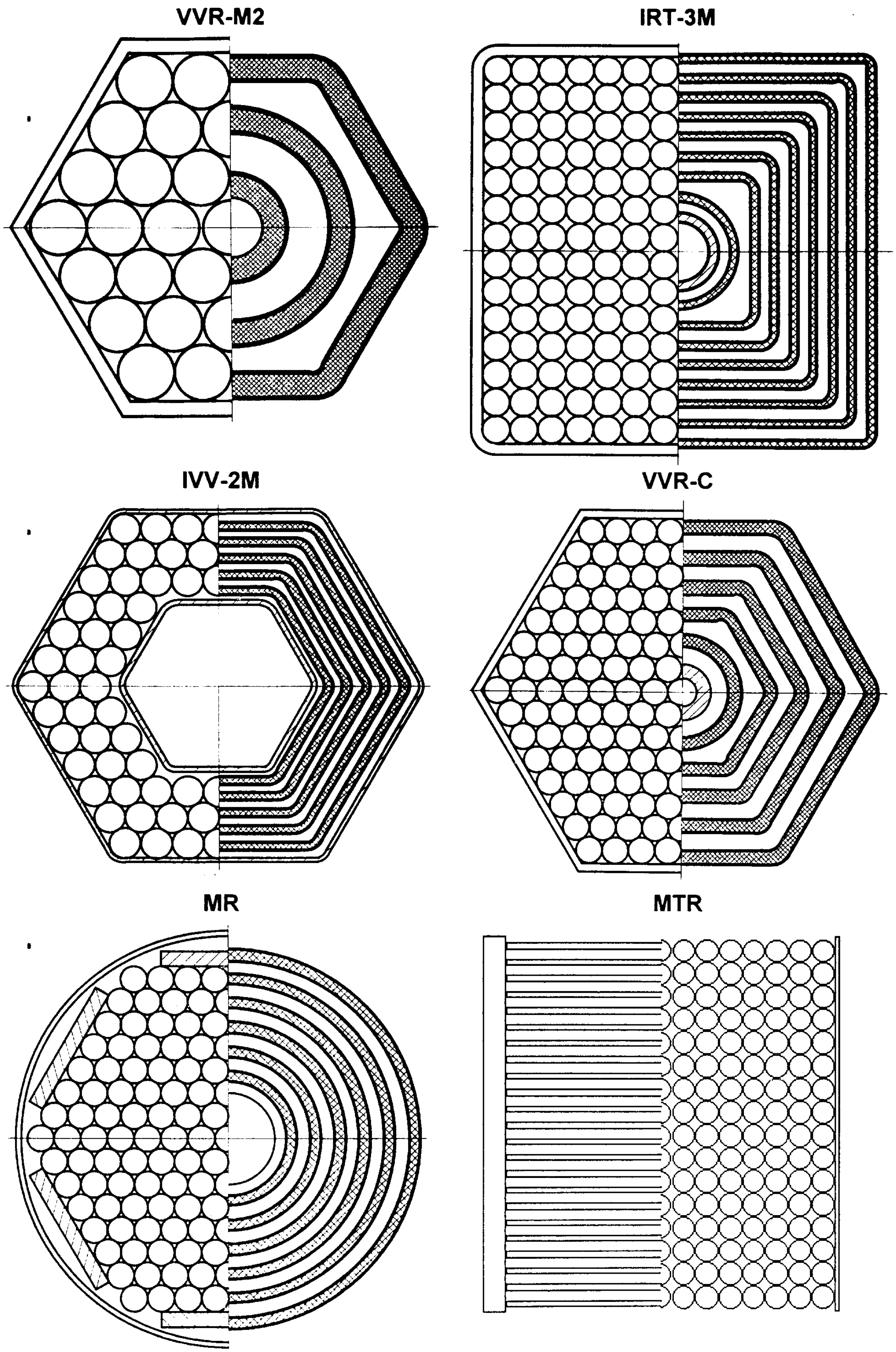

Figure 2. Schemas of Fuel Assembly Cross-Sections

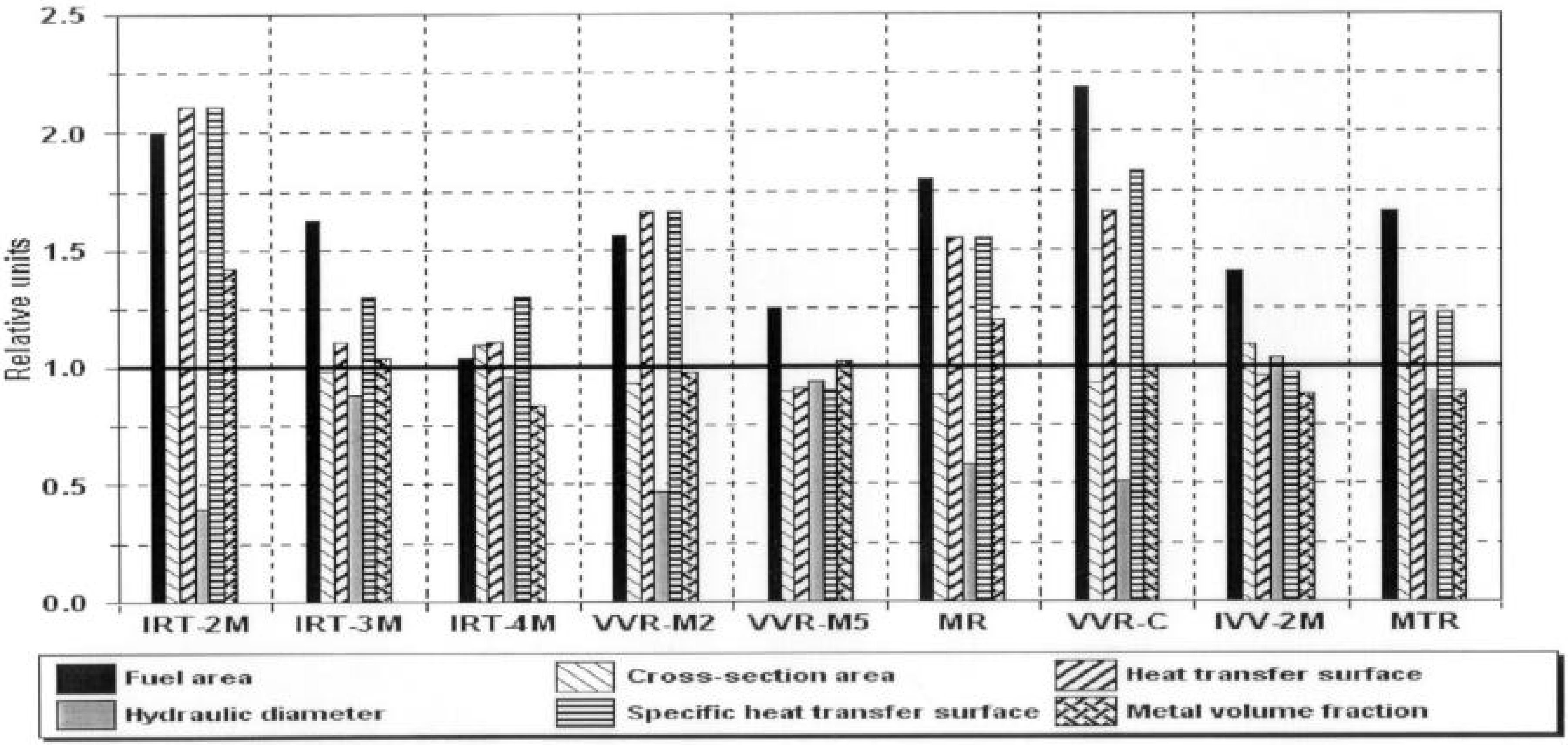

Figure 3. Comparison of Geometric Characteristics of Fuel Assemblies with Rod and Tubular Elements

matrix with internal hole of the complex form. The electroerosive method is chosen for matrixes manufacturing. This method provides necessary accuracy of the internal hole sizes and smoothness of moulding surfaces.

The fabricating process is tested in laboratory conditions on various materials for fuel elements with the circumscribed diameters 4,85 and 5,2 mm. The materials used for fabricating of fuel element simulators are given in Table 3.

Application	Material
Cladding	Aluminum alloy AMCH-2
	Aluminum alloy B IT
	Aluminum alloy CAB-6
Sealing Plug	Aluminum alloy AMCH-2
	Aluminum alloy E 1 T
	Aluminum alloy CAB-6
Meat Simulator	Mixture of an aluminum powder IIA-4 and steel powder

Table 3. Initial materials for fuel element simulators manufacturing

The core, shell and sealing plug blanks were made by turning. Then chemical processing was carried out and complex blank was assembled (Figure 4). The complex blank was moulded through the calibration matrix with deformation 5-9% for assurance of a contact between cladding and fuel core. Then it was heated and extruded by means of hydraulic press with 100 tons effort through moulding rig. The simulator of fuel element was curled to the given angel by the special facility. The cross-section of the fuel element simulator is shown on Figure 5. The basic characteristics of fuel element simulators are submitted in Table 4.

Parameter	Value
Length, mm.	600 - 700
Circumscribed Diameter, mm	4,9 - 5,2
Square Side Dimension, mm	2,9 - 3,05
Rib Sizes: Width, mm	0,4 - 0,5
Height, mm	0,6 - 0,75
Cladding Thickness, mm	0,3 - 0,35
Volume Fraction of Hard Particles, %	20 - 40
Sizes of Hard Particles, micron	60 - 160

Table 4. Technical characteristic

The fabricating investigations have shown an opportunity of manufacturing the rod fuel elements of chosen shape with uniform cladding thickness and with uniform distribution of hard particles in the meat.

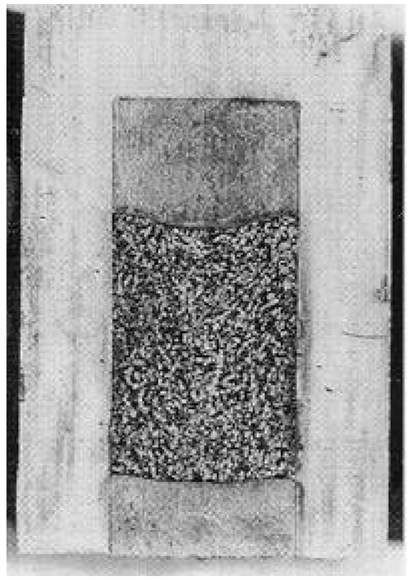

Figure 4. Blank for Fuel Element Extrusion

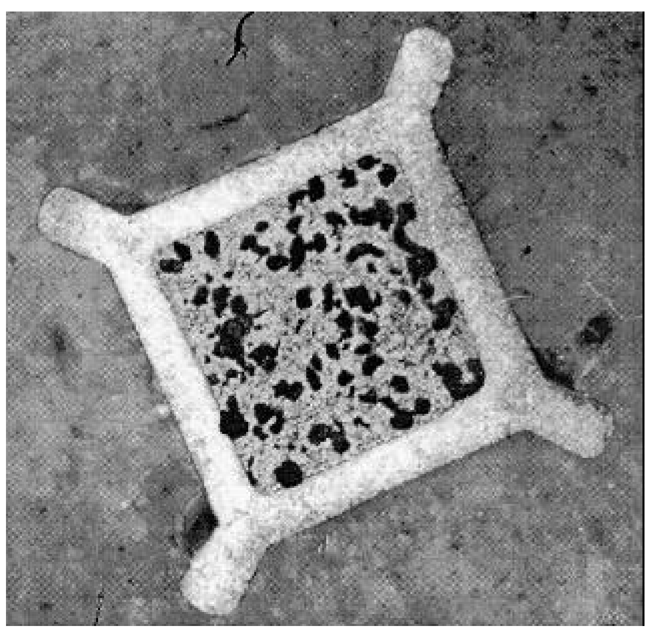

Figure 5. Cross-section of Fuel Element Simulator

On the basis of results of researches and manufacturing experience of tubular fuel elements of a various shape, the basic fabricating scheme of rod fuel elements is developed. This scheme is given in Figure 6. For comparison the fabricating scheme of tubular fuel elements manufacture is shown in the same. The rated capacity of the equipment is given in brackets.

The fabricating process of the rod fuel elements can be divided into the following basic stages:

- Preparation of a fuel composition;
- Manufacturing of fuel elements meat;
- Manufacturing of shells and sealing plugs;
- Complex blank assembling and extrusion;
- Quality control.

It can be seen in Figure 6, that the manufacture of rod fuel elements becomes considerably more simple in comparison with tubular one.

- There is no machining of meats. The suitable output is increased up to 87 % in comparison with 50 % for tubular fuel elements.
- There are no calibration dragging to provide the necessary size and shape. The complex and expensive tools are not required.
- The amount of the tools decreases about 100 times. 12 units of the tools are necessary for one size rod fuel elements manufacturing. For changing of fuel element size only the other moulding matrix is required. Other tools do not vary. For comparison, in the case of tubular fuel elements of one size it is required the more complex set of the tools the amount of which is 25 units. Taking into account, that the nomenclature of fuel elements for research reactors consists of approximately 40 various types and sizes, the needed amount of the tools achieves to 1000 units.
- The smaller capacity of equipment is necessary for rod fuel elements manufacturing. The press capacity is reduced 2,5-5 times. Its cost is reduced much the same times.
- The shape of rod fuel element is more convenient for extrusion and so allows to increase the contents of nuclear fuel in the meat to 50 volume percents in comparison with 36 volume percents for some tubular fuel elements.

CONCLUSION

1. Comparative computational investigations of rod and tubular type fuel assemblies are carried out. The fabricating process of rod fuel elements is developed. Full-scale models of rod fuel assemblies of VVR-M and IRT-M types are produced. The analysis of fabricating process of rod and tubular type fuel elements was carried out.
2. It is shown, that the fuel assemblies with rod fuel elements allow to replace assemblies with tubular type fuel elements practically in all research reactors without any changes of existing overall dimensions and configurations of the reactor cores.
3. The fabricating process of rod fuel elements is simpler. It allows completely to automate the process of fuel elements manufacturing and to decrease the cost.
4. The rod fuel elements allow to solve a problem of nuclear fuel enrichment reduction more simply through increasing of core volume and increasing up to 50 volume percents of a technological limit of a nuclear fuel loading.

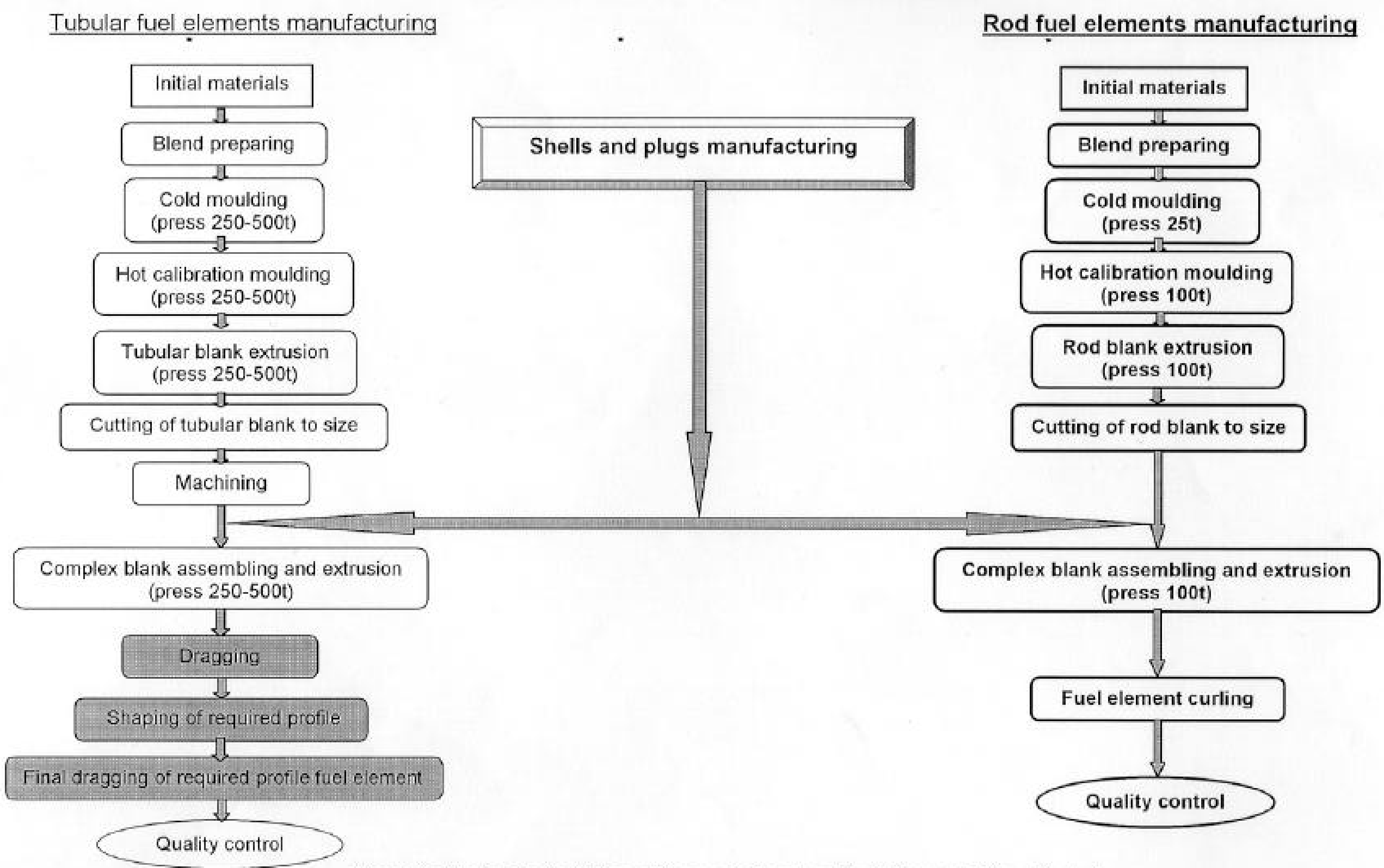

Figure 6. Technological Plan of Research Reactors Fuel Elements Manufacturing

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