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Coupled Fast-Thermal System at the "RB" Nuclear Reactor

by

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(E 36.00) INIS DESCRIPTORS:

R-B reactor: M1; coupled reactor cores: Q1; specifications; reactor safety; reactor accidents.

The results of the analyses of the possibility of the coupled fast-thermal system (CFTS) design at the "RB" nuclear reactor are shown. As the proof of the theoretical analyses the first stage CFTS-1 has been designed, realized, and tested. The excellent agreement between the results of the CFTS-1 studies and the theoretical predictions opens a straight way to the second, the final stage — realization of the designed CFTS at the "RB" nuclear reactor.

1. Introduction

The RB nuclear reactor at the Nuclear Engineering Laboratory of the "Boris Kidrič" Institute of Nuclear Sciences was the first, zero power, bare, heavy water critical facility in Yugoslavia [1]. The natural metal uranium fuel elements, the 2% enriched metal uranium fuel elements, and 80% enriched uranium dioxide fuel elements are available from 1975.

The investigation of the fast neutron fields at the RB reactor was initiated in 1976. At the time, these studies were performed on the NEUTRON CONVERTER (NC) using 80% enriched uranium dioxide fuel elements. The NC transforms the RB thermal leakage neutron flux into a fast fission neutron flux [1]. Since then the research has been focused on the determination of the characteristics of the NC. The principal advantages of the NC are easy accessibility to the large experimental space and the possibility of the fast neutron spectrum down-shifting using screens of various materials. The shortcoming of the NC is the low intensity of the fast neutron flux. This is particularly relevant to irradiation experiments.

The intensity of the fast neutron flux was up-graded in 1982 when an EXPERIMENTAL FUEL CHANNEL (EFC) was constructed. The EFC was formed of modified 80% enriched UO_2 fuel elements in a standard fuel element channel of the RB reactor [3]. The higher intensity of the fast neutron flux was the result of a smaller experimental space and the softening of the fast neutron spectrum.

Almost simultaneously in 1981, a feasibility study on the COUPLED FAST-THERMAL SYSTEM (CFTS) began. It was based on the know-how acquired through the work on the NC and the EFC and the theoretical methods and numerical codes for fast neutron fields developed at the Nuclear Engineering Laboratory.

The goal was the realization of the CFTS at the RB reactor using existing nuclear fuel with minimal reactor system modification. It was achieved at the end of 1983. The first version of the coupled fast-thermal system, CFTS-1, that is completely controlled by the existing RB reactor control and safety systems has been completed and studied [4].

Very thorough safety analyses were performed for possible accidents during the operation of the RB reactor as a coupled system. It was shown that the operation of the RB reactor as CFTS is completely safe if the existing RB control and safety systems operate properly. Neither the system components nor the staff will be exposed to higher doses during serious accidents. The safety system of the RB reactor can quickly and safely shut-down the reactor during the most probable accidents.

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2. Coupled Fast-Thermal System Design at the RB Reactor

2.1. Basic Requirements

All the calculations for the CFTS design on the RB reactor were performed using numerical codes developed at the Nuclear Engineering Laboratory [5, 6, 7].

The world well-known coupled fast-thermal reactors, especially ZPR-V [8], STEK [9] and STARK [10], were thorough studied before the CFTS design at the RB reactor has been initiated.

The basic requirements for the CFTS design at the RB reactor were set as following [4]:

(*1*) the CFTS must be formed using existing RB fuel elements with minimum possible modification of the RB reactor systems;
(*2*) the CFTS must be operated safely with existing RB control and safety systems;
(*3*) the CFTS fast core should have the highest possible ratio of the fast to thermal fissions using RB fuel elements; and
(*4*) the nuclear kinetics characteristics of the CFTS thermal core should be dominate and so determine the kinetics behaviours of the whole CFTS.

2.2. CFTS Optimal Configuration

After all the RB reactor characteristics (quality and quantity of fuel elements and moderator, safety rods position, etc.) had carefully been analyzed in regard to requirements for the CFTS it was found that a 400 mm diameter of the fast zone of the CFTS in the centre of the RB core with 120 mm square thermal lattice pitch is the technical and the nuclear optimum [4].

The CFTS fast zone should be formed in two separate aluminium tanks, each as high as the RB tank. The outer aluminium tank with 400 mm diameter should contain the blanket formed of the RB natural uranium fuel elements. The 72 natural U fuel elements (25·4 mm diameter, 2100 mm height of metal uranium in 1 mm thick aluminium cladding) should be set in two concentric rows, each one as close as possible to the other. The effective width of the blanket annulus would be 39 mm.

The fast core of the CFTS should be formed in the inner aluminium tank (300 mm diameter) inside of the blanket.

The thermal zone of the CFTS should have the inner radial heavy water reflector, thermal core of the 2% enriched metal U and 80% enriched UO_2 RB fuel elements and outer radial and bottom axial heavy water reflector.

For the reason of the high efficiency the safety rods should drop in the inner radial heavy water reflector.

The thermal core of the CFTS formed in 120 mm square RB lattice pitch should contain the inner ring of 28 fuel elements of the 80% enriched UO_2 and the outer ring of 36 fuel elements of the 2% enriched U in the D_2O moderator.

A sketch of the axial and radial cross-section of the CFTS at the RB reactor is shown in Fig. 1.

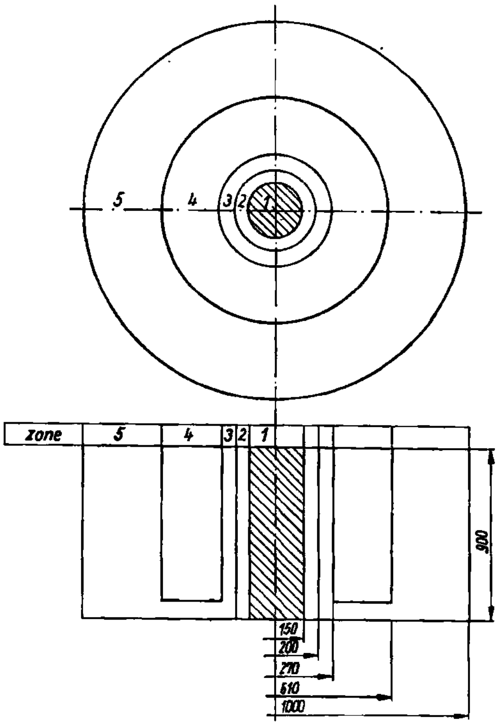

Fig. 1. CFTS axial and radial cross-section at the RB reactor (dimensions in mm)

Zones and their composition: *1* CFTS fast core (80 % enriched UO_2); *2* CFTS fast core's blanket (natural uranium); *3* D_2O inner reflector; *4* CFTS thermal core, lattice pitch 12 cm (2 % enriched U and 80 % enriched UO_2 fuel, D_2O moderator); *5* D_2O outer radial reflector

Table 1. The CFTS fast zone composition

Zone	Inner/outer diameter in mm	Material	Volume fraction in %
Fast core	0/300	uranium	9·75
		aluminium	22·05
		air	68·20
Blanket	300/400	uranium	62·49
		aluminium	10·40
		air	27·10

Table 2. The total fission distribution in the CFTS

Fast core U enrichment in %	Total fission distribution in the CFTS in % thermal core	U blanket	fast core
2	74·4	21·9	3·7
10	71·0	21·1	7·9
20	68·5	20·8	10·7
30	66·4	20·7	12·9
40	64·5	20·6	14·9
50	62·7	20·4	16·9
60	61·0	20·3	18·7
70	59·3	20·1	20·6
80	57·9	20·0	22·1

The material composition and the geometry dimensions of the RB reactor components (fuel, moderator, tank, etc.) are known with high reliability. The volume fractions of the fast zone of the CFTS at the RB reactor are shown in Table 1.

The 4-group nuclear constants for all zones of the CFTS are determined by multigroup cell code VESNA [5]. The nuclear constants for the CFTS fast core are calculated for the interval of the uranium fuel enrichment 0·7% up to 80%.

The CFTS at the RB is calculated by multigroup codes AVERY [6] and SAN [11]. Both codes are one-dimensional in cylindrical geometry developed on the collision probability method. The AVERY code is an extended SAN code with *Avery* parameters calculation for the coupled systems [12].

The complete results of the SAN and AVERY codes calculations are presented in [4]. The main results that determine the uranium fuel enrichment in the CFTS fast core, in agreement with requirement (*3*), are shown in Table 2.

According to that it was decided to use the 80% enriched UO_2 RB fuel elements [2] for the CFTS fast core composition.

The 4-group calculation with SAN code has shown that in the 80% enriched UO_2 fast core of the CFTS the 23·5% fissions are caused by fast neutrons ($E > 0\cdot 8$ MeV), 41% by intermediate neutrons ($4\cdot 65$ keV $< E < 0\cdot 8$ MeV), 19% by epithermal neutrons ($0\cdot 465$ eV $< E < 4\cdot 65$ keV) and only 16·5% by thermal neutrons ($E < 0\cdot 465$ eV).

2.3. *CFTS Nuclear Characteristics*

The nuclear characteristics of the CFTS at the RB nuclear reactor are determined [4] by SAN and AVERY codes. It is shown that existing control and safety systems can completely and safely operate RB with CFTS.

The *Avery* parameters of CFTS at the RB and STARK [10] are compared in Table 3, together with the other characteristics.

The 4-group spatial neutron flux distribution and the fast core neutron spectrum (in the 25 energy groups of the BNAB structure [13]) are shown in [4].

According to very long total neutron prompt lifetime the general time behaviour of the CFTS is very similar to

Table 3. The CFTS and STARK characteristics

Characteristics	STARK [9]	CFTS at the RB [4]
1. *Fast core*		
1.1. Outer radius (in mm)	189	150
1.2. Composition	7·57 % ^{235}U	9·75 % UO_2 (80 % ^{235}U)
(in volume %)	65·53 % ^{238}U	22·05 % Al
	26·90 % Al_2O_3	68·20 % air
1.3. $d\varrho_D/dT_f^*$ (in 1/K)	—	$+6\cdot 3 \times 10^{-7}$
2. *U blanket*		
2.1. Outer radius (in mm)	239	202
2.2. Width (in mm)	50	50
2.3. Composition	0·72 % ^{235}U	62·5 % UO_2 (0·7 % ^{235}U)
(in volume %)	99·28 % ^{238}U	10·4 % Al
		27·1 % air
2.4. $d\varrho_D/dT_f^*$ (in 1/K)	—	$-8\cdot 1 \times 10^{-7}$
3. *Fast zone nuclear Avery parameters*		
k_{FZ}	—	0·4437
k_{11}	0·7610	0·7370
k_{12}	0·1316	0·1758
l_{12} (in μs)	67·55	197·03
l_{11} (in μs)	7·09	34·16
l_1 (in μs)	21·47	76·99
S_1 (in %)	35·0	40·4
α_1	0·411	0·479
4. *Thermal zone*		
4.1. Radius (in mm)		
— inner	305	270
— outer	460	606
4.2. Composition	15·40 % U_3O_8 (20 % ^{235}U)	28 UO_2 (80 % ^{235}U)
(in volume %)	35·96 % H_2O	fuel elements, $l = 120$ mm;
	48·64 % graphite	36 U (2 % ^{235}U)
		fuel elements, $l = 120$ mm;
		D_2O moderator
4.3. Reflectors	graphite (100 %)	D_2O (1·2 % mol. H_2O)
width (in mm)		
— inner radial	66	64
— outer radial	400	396
— bottom axial	—	100
4.4. Reactivity coefficients		
$d\varrho_D/dT_f^*$ (in 1/K)	—	$-2\cdot 7 \times 10^{-6}$
$d\varrho/dT_m^*$ (in 1/K)	-5×10^{-5}	$-3\cdot 0 \times 10^{-4}$
$d\varrho/dV$ (void) (in 1/%)	-1×10^{-3}	—
5. *Thermal zone nuclear Avery's parameters*		
k_{TZ}	—	0·8430
k_{22}	0·8330	0·7582
k_{21}	0·3023	0·3576
l_{22} (in μs)	122·6	504·7
l_{21} (in μs)	101·2	473·1
l_2 (in μs)	119·0	497·0
S_2 (in %)	65·0	59·6
α_2	0·589	0·521
6. *CFTS nuclear characteristics*		
Critical level (in mm)	700	900
l (in μs)	78·9	187·8
β_{eff}	$7\cdot 7 \times 10^{-3}$	$7\cdot 5 \times 10^{-3}$ (estimated)
$d\varrho_D/dT_f^*$ (in 1/K)	—	$-3\cdot 0 \times 10^{-6}$
$d\varrho/dT_m^*$ (in 1/K)	—	$-3\cdot 0 \times 10^{-4}$
$P_{nominal}$ (in W)	1·0	1·0

* Isothermal coefficient.

that of a thermal system. Analyzing the coupling coefficients it can be seen that CFTS can be shut down by existing RB safety system acting only upon the thermal region.

It can be seen that $d\varrho_D/dT_f$ of the CFTS fast core is positive but very small thanks to high dilution of the 80% enriched RB fuel elements. The total isothermal $\partial\varrho/\partial T_f$ and $\partial\varrho/\partial T_m$ are negative making the CFTS inherent safe, and so there is no need for additional safety rods acting on the fast core.

As the isolated fast zone multiplication factor k_{FZ} is very low and according to conclusions above it follows that CFTS at the RB reactor can be operated as safely as a thermal RB reactor without changes of control or safety systems.

This conclusion is confirmed by the results of the preliminary safety analyses [4] by MACAN code [7].

3. CFTS-1, the First Stage of the CFTS

3.1. *CFTS-1 Configuration*

The CFTS-1 configuration represents the first stage of CFTS at the RB reactor. It is designed according to the requirements (*2.1.*) and realized at the RB reactor. The checking of the applied theoretical methods and the numerical codes at the CFTS-1 is the main reason of the CFTS-1 realization.

The fast zone of the CFTS-1 has the same configuration as designed optimal CFTS at the RB reactor (*2.2.*) except that the fast core of the CFTS-1 is made as 80% UO_2 fuel annulus with 200 mm central air gap.

The radial cross-section of the CFTS-1 fast zone is shown in Fig. 2.

The radial and axial cross-sections of the CFTS-1 realization at the RB are shown in Figs. 3 and 4.

It was shown [4] that existing RB aluminium construction can carry inhomogeneous fuel and moderator loading in the RB tank without any additional supports.

3.2. *CFTS-1 Nuclear Characteristics*

The 4- or 2-group nuclear constants for all the material zones of the CFTS-1 are determined by multigroup cell code VESNA.

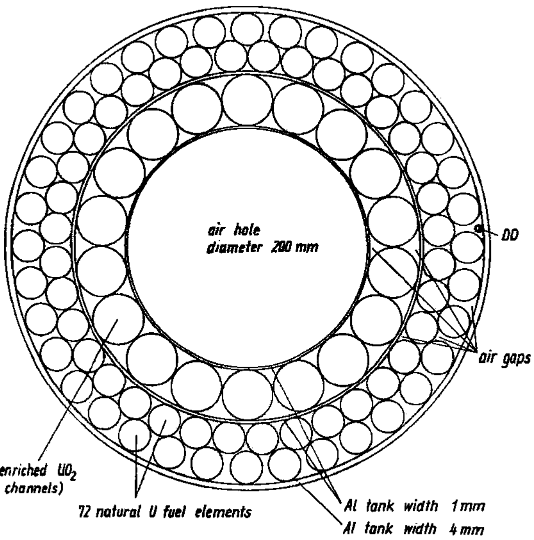

Fig. 2. CFTS-1 fast zone cross-section at the RB reactor

filling detector connected in RB safety system *DD* D_2O

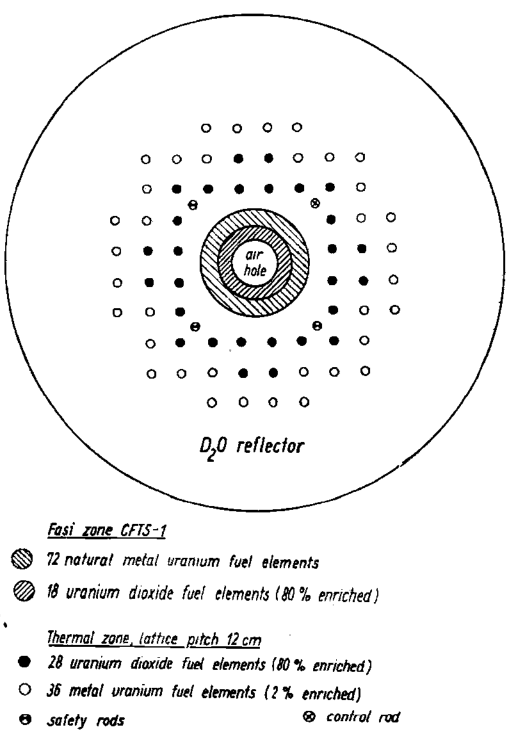

Fig. 3. RB reactor core configuration with CFTS-1

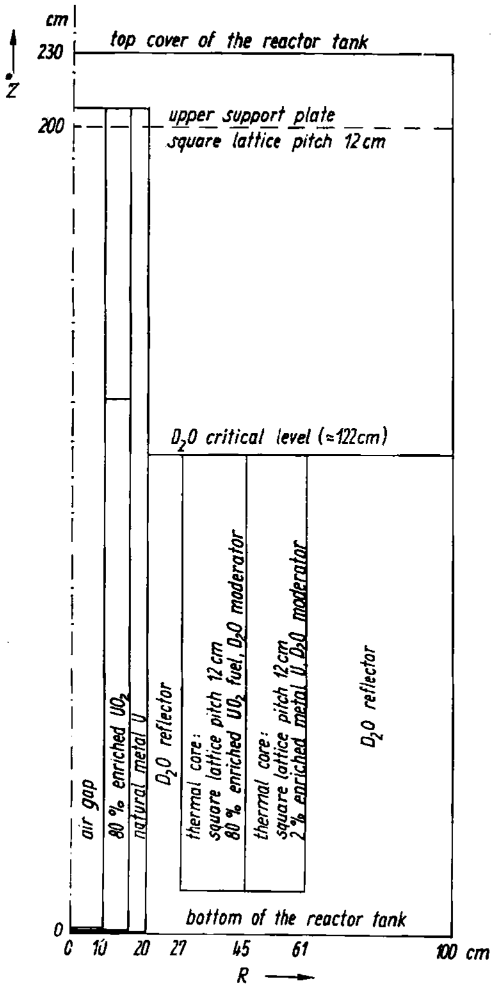

Fig. 4. Axial cross-section of the CFTS-1 at the RB reactor

Table 4. Critical heavy water level of the CFTS-1

Experiment	$H_c = (122{\cdot}46 \pm 0{\cdot}01)$ cm, $T_{D_2O} = 17{\cdot}4°$ C
SAN code	$H_c = (120 \pm 5)$ cm, $B_z^2 = 6{\cdot}2$ m^{-2}
IZGOR code	$H_c = (128 \pm 6)$ cm

The CFTS-1 at the RB reactor is calculated by multigroup codes SAN, AVERY and IZGOR. The IZGOR code [14] is the IBK-NET version of the well-known two-dimensional, few group, diffusion TWENTY GRAND code [15]. In the case of the IZGOR code the central air zone parameters are determined by Monte Carlo method according to the model in [16].

Determined critical heavy water level of the CFTS-1 at the RB reactor is in good agreement with the experiment (Table 4).

Table 6. Central air gap flux ratio

g	Energy interval	Φ_g^c/Φ_1^c
1	0·8 MeV to 10·5 MeV	1·00
2	4·65 keV to 0·8 MeV	0·45
3	0·465 eV to 4·65 keV	0·78
4	1 meV to 0·465 eV	0·26

The *Avery* parameters of the CFTS-1 at the RB reactor, together with the other characteristics, are shown in Table 5 [4].

Only 2·51% of total fissions occur in the fast core, 19·31% in the U blanket, and 78·19% in the thermal core of the CFTS-1 [4]. The 4-group radial distribution of the neutron flux in the CFTS-1 is determined [4] by AVERY

Table 5. The CFTS-1 characteristics

Characteristics	CFTS-1 at the RB [4]
1. *Fast Core*	
1.1. Central air gap radius (in mm)	100·0
1.2. Core outer radius (in mm)	150·0
1.3. Core volume composition	9·3 % UO_2 (80 % ^{235}U) 23·8 % Al 66·9 % air
1.4. $\mathrm{d}\varrho_\mathrm{D}/\mathrm{d}T_\mathrm{f}^*$ (in 1/K)	0
2. ***U blanket***	
2.1. Outer radius (in mm)	202
2.2. Width (in mm)	50
2.3. Composition (in volume %)	62·5 % U (0·7 % ^{235}U) 10·4 % Al 27·1 % air
2.4. $\mathrm{d}\varrho_\mathrm{D}/\mathrm{d}T_\mathrm{f}^*$ (in 1/K)	$-7{\cdot}34 \times 10^{-6}$
3. ***Fast zone nuclear Avery's characteristics***	
k_{FZ}	0·1571
k_{11}	0·4523
k_{12}	0·1526
α_1	0.2144
S_1 (in %)	21·8
l_{11} (in µs)	79·6
l_{12} (in µs)	209·0
l_1 (in µs)	149·1
4. ***Thermal zone***	
4.1. Radius (in mm)	
– inner	270
– outer	606
4.2. Composition	28 UO_2 (80 % ^{235}U) fuel elements 26 U (2 % ^{235}U) fuel elements in D_2O (1·20 mol. H_2O) moderator 120 mm square lattice pitch D_2O (1·20 % mol. H_2O)
4.3. Reflectors width (in mm):	
– inner radial	64
– outer radial	396
– bottom axial	100
4.4. ***Reactivity*** coefficients	
$\mathrm{d}\varrho_\mathrm{D}/\mathrm{d}T_\mathrm{f}^*$ (in 1/K)	$-4{\cdot}9 \times 10^{-6}$
$\mathrm{d}\varrho/\mathrm{d}T_\mathrm{m}$ (in 1/K)	$-4{\cdot}62 \times 10^{-4}$
5. ***Thermal zone nuclear Avery's parameters***	
k_{TZ}	0·9738
k_{22}	0·8505
k_{21}	0·5363
α_2	0·7856
S_2 (in %)	78·2
l_{22} (in ms)	0·524
l_{21} (in ms)	0·171
l_2 (in ms)	0·517
6. ***CFTS-1 nuclear characteristics***	
Critical D_2O level (in mm)	1224·6
l (in ms)	0·365
β_{eff}	$7{\cdot}5 \times 10^{-3}$ (estimated)
$\mathrm{d}\varrho_\mathrm{D}/\mathrm{d}T_\mathrm{f}^*$ (in 1/K)	$-1{\cdot}22 \times 10^{-5}$
$\mathrm{d}\varrho/\mathrm{d}T_\mathrm{m}^*$ (in 1/K)	$-4{\cdot}62 \times 10^{-4}$
P_{nominal} (in W)	1·0

* Isothermal coefficient.

code. The neutron flux ratio in the centre of the air gap of the fast core is shown in Table 6.

The flux of thermal, epithermal and fast neutrons in the air gap centre is determined by absolute measurements of the activity of the irradiated Au and S foils [4]. For 1W of the RB-CFTS-1 power is obtained (standard deviation errors are shown):

$$\Phi_{\text{th}} = (2.30 \pm 0.08) \times 10^5 \text{ n/cm}^2\text{ s},$$

$$E_{\text{n}} < 0.625 \text{ eV}$$

$$\Phi_{\text{epi}} = (1.13 \pm 0.05) \times 10^6 \text{ n/cm}^2\text{ s},$$

$$E_{\text{n}} \approx 4.9 \text{ eV},$$

$$\Phi_{\text{f}} = (1.37 \pm 0.20) \times 10^6 \text{ n/cm}^2\text{ s},$$

$$0.8 \text{ MeV} < E_{\text{n}} < 10.5 \text{ MeV}.$$

The fast neutron spectrum in the air gap centre is determined by threshold detectors of In, S, Al, Fe, and Mg and compared with the calculated one by VESNA code [4]. It was found good agreement in spite of the small number of the available threshold detectors and application of the effective threshold method. The activity determination for irradiated foils is done by ACT code [17] developed in the IBK-NET laboratory.

3.3. *CFTS-1 Accident Analyses*

According to the very long total prompt neutron lifetime of the CFTS-1 (Table 5) the general time behaviour of the CFTS-1 is similar to the RB reactor. The coupling *Avery*'s coefficients and the negative reactivity coefficients show that CFTS-1 at the RB can be safely operated as a thermal RB reactor without any changes in the control or safety systems.

Very thorough accidental analyses were performed by MACAN code for possible accidents during CFTS-1 operations. The kinetics and dynamics parameters are taken out from Table 5 (l, β, $\mathrm{d}\varrho/\mathrm{d}T$) or from [18, 19] ($\lambda_i$, β_i), or were determined in the experiments with the CFTS-1 [4].

The 6 delayed and 8 photodelayed neutron groups are taken into account.

The total reactivity of the RB safety rods is determined by the rod-drop method as $-(0.053 \pm 0.003)$. In the first second only the two safety rods drop in the core with total reactivity of $-(0.034 \pm 0.002)$. In the accidental analyses it is calculated with -0.035 value of the RB safety rods with 1 s drop-in time according to the linear time function:

$$\varrho_{\text{sr}} = -0.035t, \qquad 0 \leqq t \leqq 1 \text{ s}.$$

The maximum of the heavy water excess over the critical level is determined by the safety RB maximum level meter (MLM) and is calculated as equivalent to the reactivity value of 0.006.

According to the experimentally determined change of the reactivity of the CFTS-1 with changing of the D_2O level over the critical level

$$\frac{\partial \varrho}{\partial H} = (173 \pm 5) \times 10^{-5} \text{ 1/cm},$$

and according to the two possible speeds of the heavy water level increasing in the RB tank ($U_{\text{s}} = 0.8$ cm/min and $U_{\text{f}} = 2.4$ cm/min) the linear reactivity rates are determined as:

$$\left.\frac{\partial \varrho}{\partial t}\right|_{\text{s}} = 2.3 \times 10^{-5} \text{ 1/s} \quad \text{and}$$

$$\left.\frac{\partial \varrho}{\partial t}\right|_{\text{f}} = 7.0 \times 10^{-5} \text{ 1/s}.$$

The power change of the CFTS-1 at the RB reactor during two of few possible accidents is shown in Figs. 5 and 6.

The special attention is payed to accidental filling of the CFTS-1 central air gap with the heavy water from the RB thermal core [4]. According to the conservative laws it is determined that the most dangerous accident is the one in which the air gaps of the three internal fast core tanks will be filled with the D_2O in the shortest time. It is estimated [4] that during only 1 s the reactivity will be increased, by linear law, to the maximum value of the 0.015.

A few of the safety analyses results are shown in Fig. 7.

According to the accidental results the radiation doses at "the critical points" in the RB building (especially in the reactor control room) are estimated and it is shown [4] that during supposed accidents neither the reactor components nor the reactor staff will be exposed to the prohibited radiation doses. The existing RB safety system can quickly and safely shutdown the reactor in the case of the most probable or the highest designed accident.

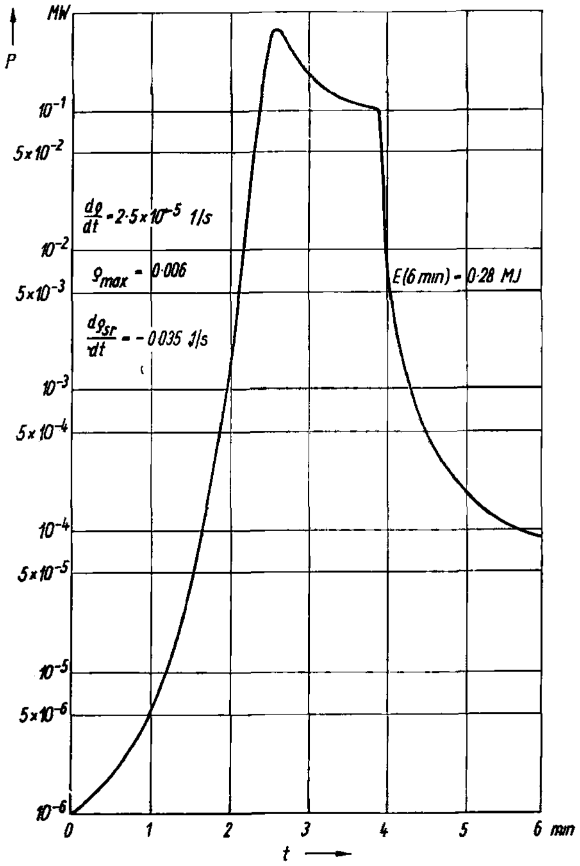

Fig. 5. Power change of the CFTS-1 at the RB reactor, according to the MACAN code, during D_2O level increasing over the critical level with lower speed until the D_2O maximum level meter (MLM) is not reached when the RB safety system is activated

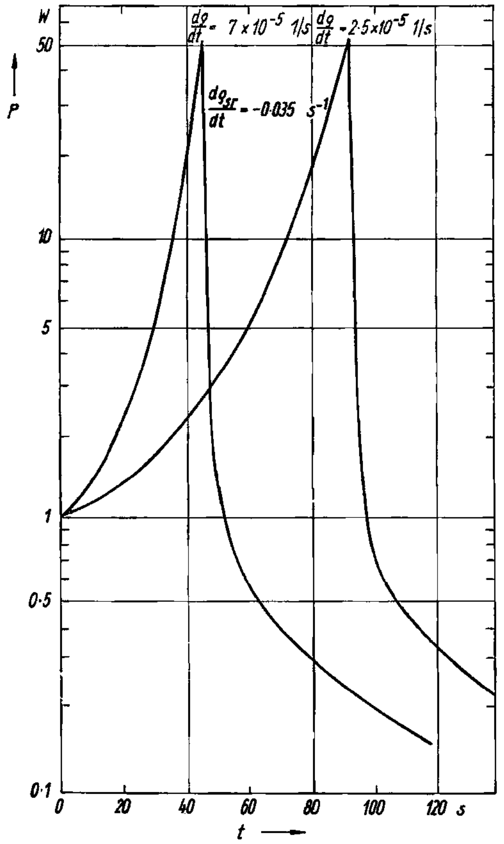

Fig. 6. Power change of the CFTS-1 at the RB reactor, according to the MACAN code, during D_2O level increasing over the critical level

The RB safety system is activated at the 50 W power level trip

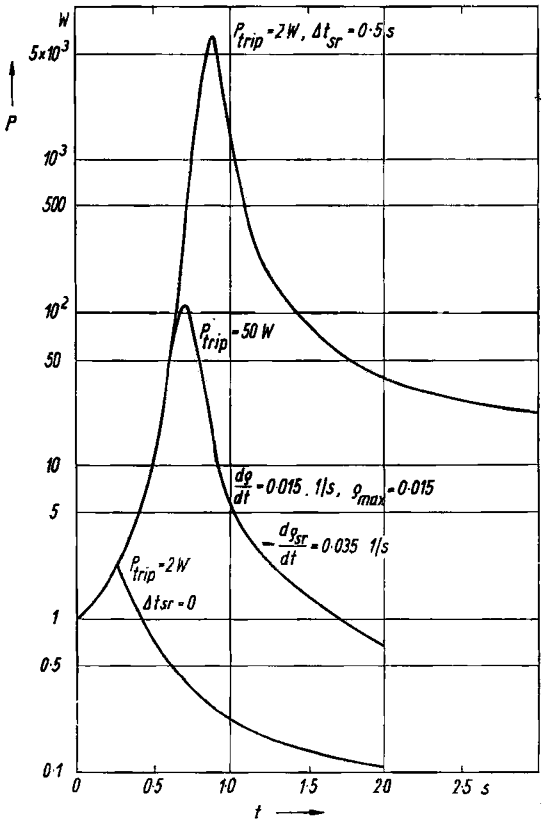

Fig. 7. Power change of the CFTS-1 at the RB reactor, according to the MACAN code, during accidental filling of the CFTS-1 fast zone air gaps with D_2O in 1 s

The RB safety system is activated at the 2 W power level trip (no delay, or 0·5 s delay) or at the 50 W power level trip (no delay)

4. Conclusion

The activity of the fast neutron fields studies was initiated in 1976 at the RB reactor when the highly enriched uranium fuel was available. The neutron converter (NC) and the experimental fuel channel (EFC) were developed. The know-how acquired and the theoretical methods and numerical codes developed at the Nuclear Engineering Laboratory were the basis for the coupled fast-thermal reactor possibility analyses.

According to the basic requirements (*2.1.*) the design analyses of the CFTS at the RB reactor are performed (*2.2.*, *2.3.*) using existing and new developed numerical codes. The nuclear characteristics of the designed optimal CFTS configuration were determined using *Avery*'s theory and after comparing with STARK coupled system the possibility realization of the CFTS at the RB reactor was proved.

The first stage, CFTS-1 as a proof of the theoretical calculation, was designed and developed at the RB reactor. The excellent agreement between the results of the CFTS-1 experimental studies and the theoretical predictions were achieved. These results open a straight way to the realization of the designed CFTS at the RB nuclear reactor.

The safety analyses performed for possible accidents have shown that the RB reactor operation with the CFTS is completely safe if the existing RB control and safety systems operate properly.

It is shown in this paper that it was possible to produce a new, coupled fast-thermal system by means of small modifications on a zero power RB research thermal reactor.

The following various goals set for the CFTS realization of the RB reactor are achieved:

(*1*) production of the first coupled fast-thermal system at the RB reactor represents the first step that would lead to the development of the fast reactor technology in Yugoslavia;

(*2*) development of the experimental methods for the fast neutron fields study;

(*3*) significant contribution in development of new theoretical methods and numerical codes for fast neutron fields computation;

(*4*) experience in dealing with fast neutron fields was attained;

(*5*) the straight way to the realization of the designed CFTS at the RB reactor was opened.

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Influence of a Transverse Magnetic Field on Phase Distribution in Liquid-Metal Two-Phase Flows

by

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(E 11.00) INIS DESCRIPTORS:

liquid metals: M1,Q2; two-phase flow: M2,Q1; magnetic fields: Q1; void fraction: Q2; diffusion, tensors; dispersions; bubbles; turbulence; velocity.

In the suggested model the influence of a magnetic field on the dispersion of gas bubbles in a liquid-metal flow is predicted on the basis of a diffusion equation. The magnetic field is taken into account by its influence on the turbulence intensity and on the relative velocity of the bubbles. The main result is the suppression of lateral distribution of gaseous phase by the magnetic field.

1. Introduction

Liquid-metal two-phase flows have growing importance for applications in liquid-metal fast-breeder reactors, liquid-metal MHD power generation systems, metallurgical systems, and fusion reactors. Within this context the knowledge of local void fraction and, in particular, possibilities to influence the phase distribution are of considerable interest. Information about local void fraction is useful e.g. for the detection of microleaks in a sodium-heated steam generator. Such a leak represents a source of small bubbles ($R \leqq 1$ mm) according to *Uhlmann* [1].

Furthermore, the knowledge of possibilities to influence the local void fraction is important e. g. for an optimization of acoustical and chemical sensors in liquid-metal devices. For a deeper insight into the complex structure of a liquid-metal two-phase flow it is necessary to have simple models to evaluate the local void fraction. In the present paper such a simple model is proposed for the influence of an external homogeneous magnetic field on the dispersion of an initially narrow void distribution in a turbulent flow of liquid sodium.

The analysis is based on a diffusion equation for the local void fraction. The influence of the magnetic field is taken into account in a very simple way, namely, only by the damping of the isotropic turbulence intensity and the decrease of relative bubble velocity. Only the influence of a transverse magnetic field is considered in the present paper because of a lack of information about the influence of a longitudinal or inclined magnetic field on drag and turbulence intensity. The main result will be that a magnetic field is able to suppress considerably the lateral distribution of gas bubbles.

2. Diffusion Theory

2.1. *Diffusion Equation*

The investigation of void distribution is based on a diffusion equation for the void fraction $\alpha(\boldsymbol{r}, t)$ derived by *Techy* and *Szabados* [2]:

$$\frac{\partial \alpha}{\partial t} + \frac{\partial}{\partial x_k}(v_k \alpha) = \frac{\partial}{\partial x_k}\left(D_{kl}\,\frac{\partial \alpha}{\partial x_l}\right). \tag{1}$$

Here $\boldsymbol{v}$ is the mean value of the bubble velocity, and the D_{kl} are the components of the diffusion coefficient tensor $\mathbf{D}$.

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