CONVERSION (UTILIZING LEU INSTEAD HEU) OF RESEARCH REACTORS IN CZECH REPUBLIC

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ABSTRACT

Paper shortly describes some advantages on the RERTR-programme in the Czech Republic. Further calculations and experimental measurements finished on the VR-1 training reactor Sparrow. Paper brings results and its evaluation as well as one-year operation experiences with the Russian fuel assemblies IRT-3M and also operation experiences with mixed Core configuration (the Russian fuel assemblies IRT-2M with enrichment 80% ^{235}U and 36% ^{235}U on the LVR-1 5 research reactor.

In the Czech Republic, conversion - exchange of HEU for LEU - has been done in 2 research reactors. These are the LVR-15 research reactor (power up to 10 -15 MW, burning IRT - 2M type fuel from Russia), operated by the Nuclear Research Institute in Rez near Prague and the VR- I training reactor (power up to 5kW, IRT-3M type fuel), operated by the Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague. Both reactors have a number of common design features, e. g. stainless steel reactor vessels (made by SKODA Nuclear Machinery, Co.), core support plate, control rods etc. Both reactors use 36% enriched U235 fuel assemblies. These institutions cooperate in the field of physical calculations, fuel exchange and sharing information. The objectives of this cooperation are:

- to use the same type of fuel enriched with 20% U235 in both reactors in a given time (after the programme has finished)
- to appropriately bum up in an appropriate way all research reactor fuel with enrichment higher than 20% U235 that still exists in the Czech Republic.

The nuclear fuel situation for research reactors in the Czech Republic is shown in Fig. 1. However, the LR-0 research reactor, operated with fuels designed for the VVER type power reactor with enrichment up to 5% U235, has not been included in this figure. Although the

amounts of different types of fuel in use are not indicated here, the past, present and future situations can be clearly seen from the figure.

At present the LVR- 15 reactor has been converted from 80% to 36% enrichment. Only one remaining fuel assembly with the original 80% enrichment will be operated for a few more days. The VR-1 training reactor has been operating with the IRT-3M type fuel since last spring. The information about the first critical experiment with this fuel was presented at the RERTR 97 conference in Jackson Hole in the USA /2/. Fig. 1 also shows the SR-0 (SKODA) reactor, the operation of which was shut down several years ago. The fuel from this reactor, operating at the power up to 5kW, was transported to the NRI in Rez.

The process of lowering fuel enrichment (mixed cycles) at the LVR-15 reactor from the original 80% to the present 36% can be seen in Fig. 2 and especially Fig. 3. Fig. 2 shows the original LVR-15 reactor core arrangement and its environment before the mixed cycles operation started up. Fig. 3 presents schematically 8 different mixed cycles with assembly numbers set-ups. The last cycle, designed marked MDC-7AI, contained, at the time we wrote our paper, only one fuel assembly with the original 80% enrichment, as mentioned above. Table 1 indicates the main features of mixed cycles existing at the LVR- 15 reactor: their total number, the number of fuel assemblies in the cycles, average bum-up, reactivity excess at the beginning (BOC) and at the end (EOC) of fuel cycles, generated power and the total amount of U235 in the core. Since the IRT-2M fuel is geometrically identical both for 80% and for 36% enrichment, and therefore interchangeable, no adjustment of the LVR-15 cooling system was necessary. Neither did any major neutron physical problems arise during this process.

A further stage is being prepared illustrated in Fig. 1, in which the IRT-2M type fuel will be gradually replaced by the IRT-3M type. The replacement will be started after all the IRT-2M fuel with 36% enrichment is burnt-up (consumed).

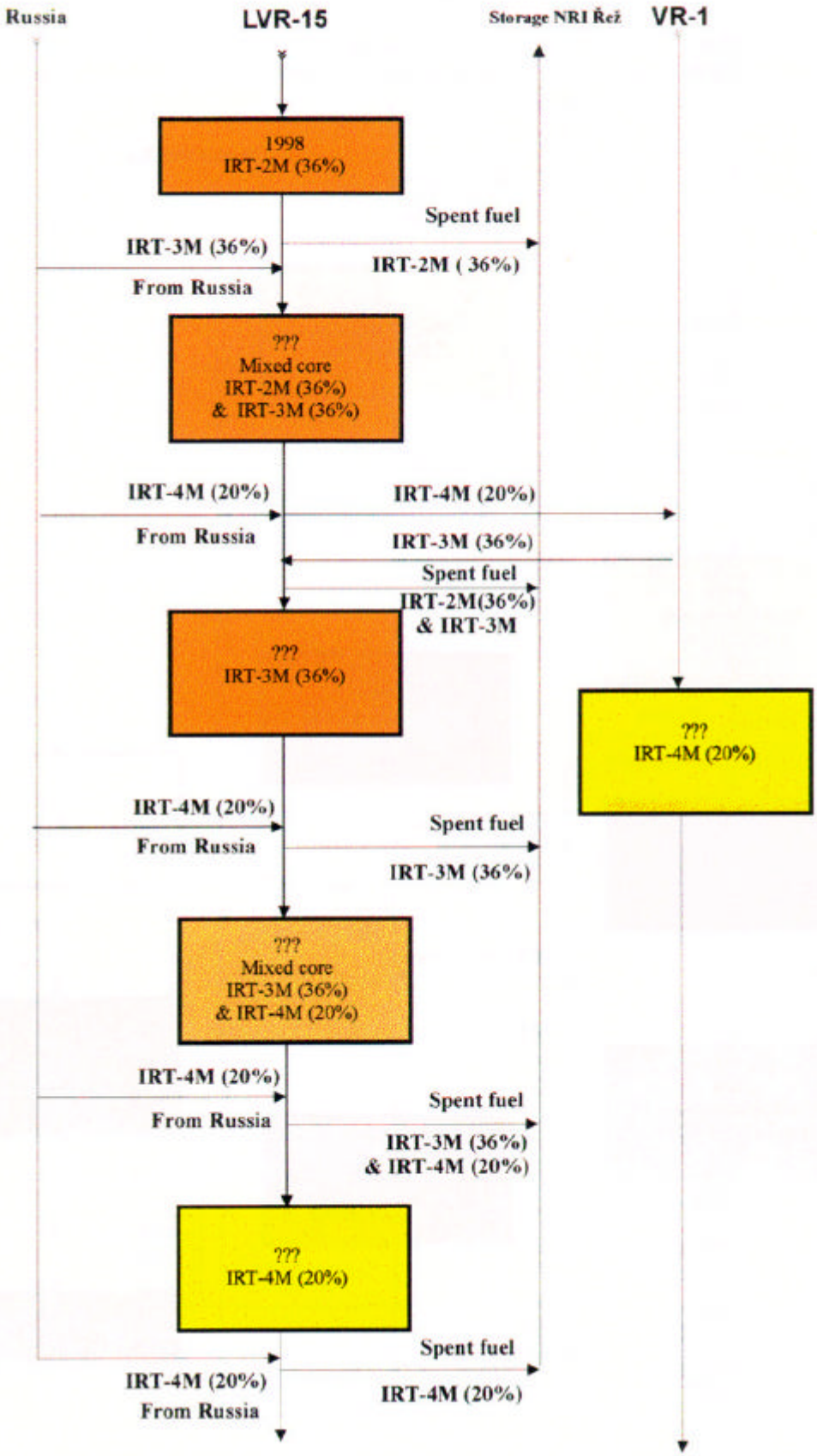
During this exchange we will concentrate on higher U235 content in the IRT-3M fuel assemblies and their thermohydraulic properties resulting from their geometry.

The VR-1 training reactor is already operated with the IRT-3 M fuel. VR-1 is a low power reactor, without any noticeable bum-up. Therefore attention is focused here on experimental data interpretation and their comparison with theoretical results. In 1998 several experiments were carried out with extreme precision, having for objective the comparison of obtained results with calculated values. The approach to the critical stage during the reactor core configuration set-up was recalculated by a MCNP programme. (See Fig. 4, where the reactor core is designated as 131). Representative experimental and calculated results are presented in Tables 2, 3 and 4. It appears that in a cool, unpoisoned reactor charged with fresh fuel the results correspond fairly well in areas not too remote from the critical stage, especially when the MCNP program is applied. When using the diffusion code DIFER (Czech origin), the differences between calculated and experimental results are bigger. (The DIFER code uses the input data calculated by WIMS-D4 code).

Also the comparison of representative configurations with IRT-2M and IRT-3M may be very interesting. IRT-3M critical configurations are generally smaller and most undermoderated. At present several new configurations are being prepared (including the compact configuration with the minimum number of fuel assemblies). We also started calculations for the reactor core charged

with IRT-4M fuel. This fuel, as shown in Fig. 1, should be enriched to less than 20% U235 and should be geometrically interchangeable with IRT-3M type. More precise parameters of IRT-4M fuel type are not known yet.

Fig. 1 Fuel-flow in Czech research reactors (1957 - 1998 - ????)
RERTR program in Czech republic (cont.)



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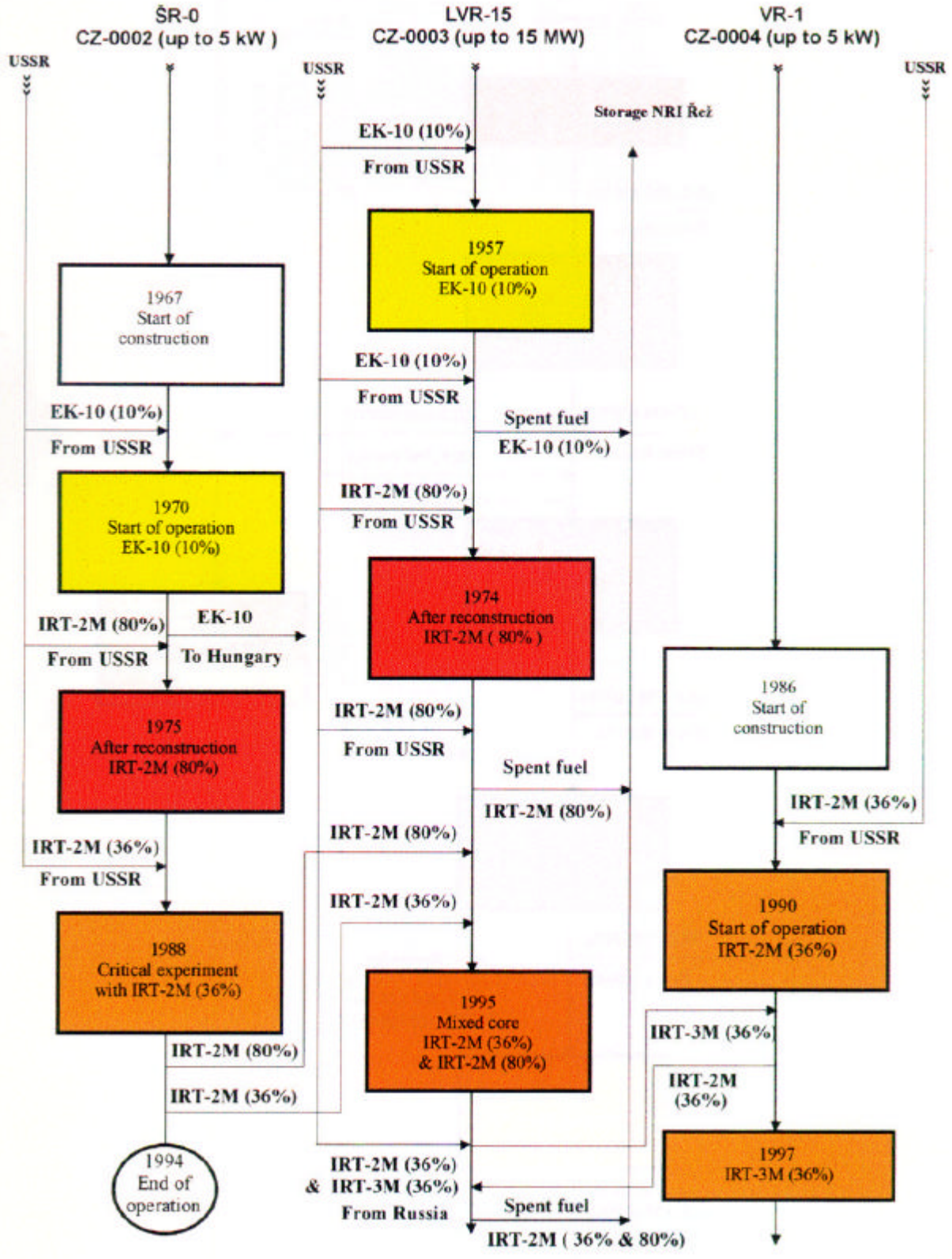
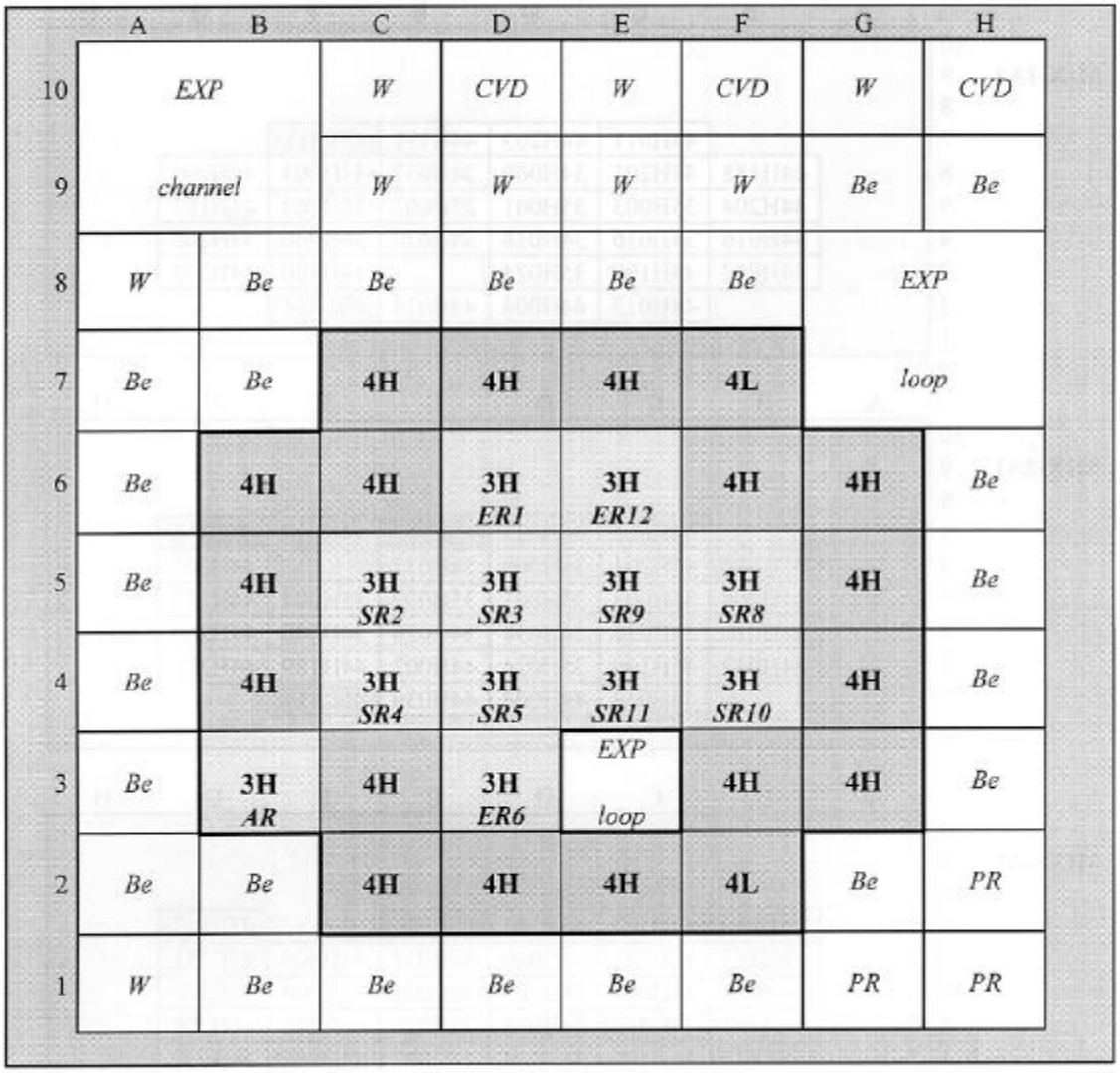


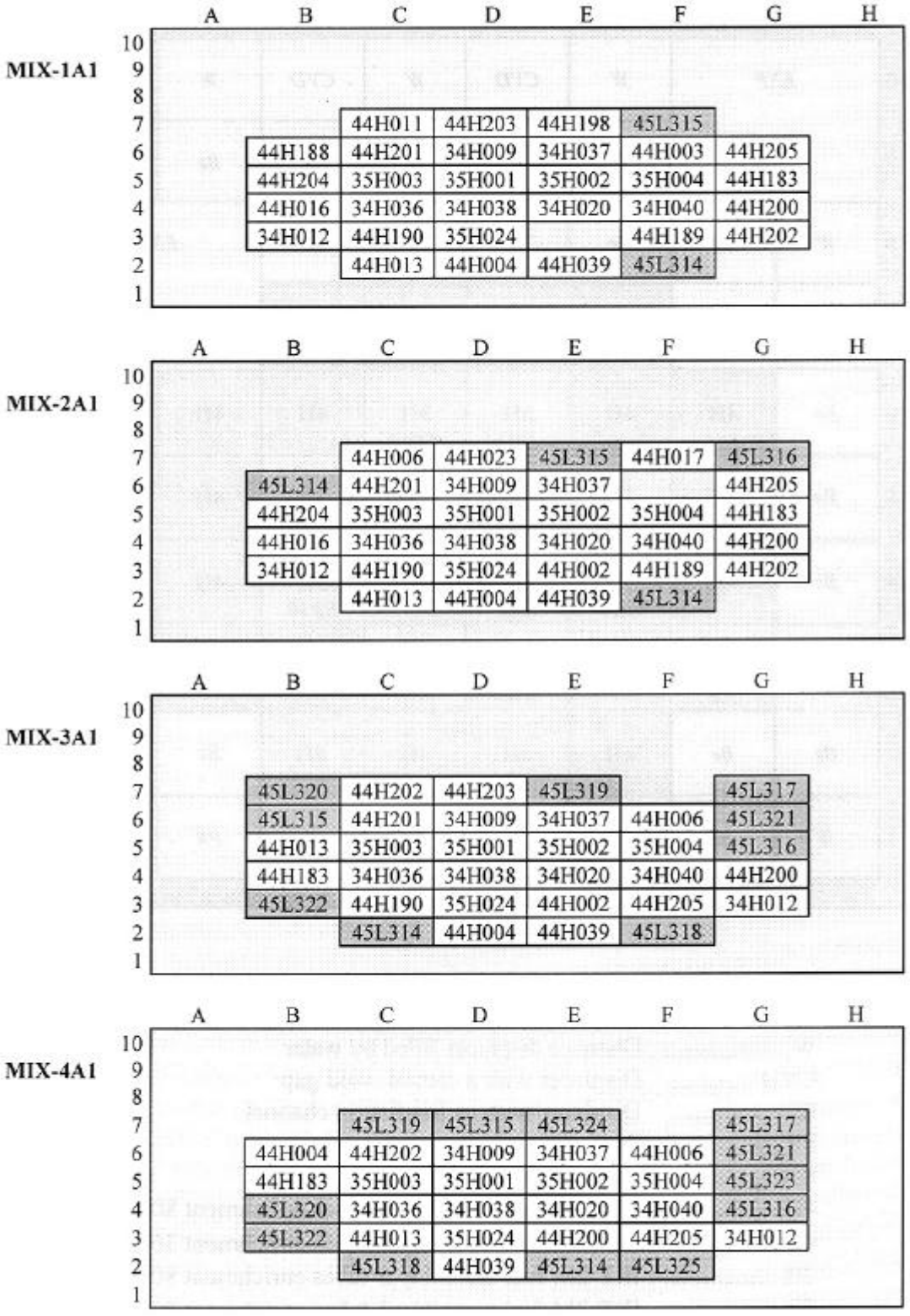
Fig. 2 LVR-15 : The Starting Mixed Core MIX-1A1



LEGEND:

Be ..... Beryllium
W ..... Distance displacer filled by water
CVD ..... Displacer with a central void gap
IC .... Displacer with an irradiation channel
PR ... . Pneumatic rabbit
EXP ..... Experimental device
4H ... . IRT-2M fuel assembly,4-tubes,enrichment 80%
4L ... . IRT-2M fuel assembly,4-tubes,enrichment 36%
3H ... . IRT-2M fuel assembly,3-tubes,enrichment 80%
M .... IRT-2M fuel assembly,3-tubes,enrichment 36%
AR .. .. Automatic regulator
SR ... . Shim rod
ER ... . Safety rod

Fig. 3 Simplified*) Schema of Gradual Conversion of the LVR-15 in Selected Steps.



H resp. L .... IRT-2M fuel assembly with enrichment 80% resp.36%

*) Changes in positioning of non-fuel components are omitted.

Fig. 3 Simplified Schema of Gradual Conversion of the LVR - 15 in Selected Steps. (cont.)

MIX-4C1

	A	B	C	D	E	F	G	H
10								
9								
8								
7			45L328	45L318	45L324		45L317	
6		45L319	44H202	34H038	34H037	44H006	45L321	
5		44H204	35L326	35H001	35H002	34H040	45L323	
4		45L320	34H036	35H003	35H004	35L327	45L316	
3		45L322	44H189	35H024	44H200	44H205	34H012	
2			45L315	44H039	45L314	45L325		
1								

MIX-5A1

	A	B	C	D	E	F	G	H
10								
9								
8								
7		45L334		45L317	45L318	45L316		
6		45L325	44H316	35L326	35L327	44H039	45L324	
5		44H012	35L329	35L319	35L320	35L332	44H040	
4		45L328	35L333	35L321	35L322	35L330	45L315	
3		45L325		35L331	44H014	45L314	34H010	
2		45L312	45L321	45L323			44H197	
1								

MIX-6A1

	A	B	C	D	E	F	G	H
10								
9								
8								
7				45L317	45L318		47L033	
6		47L034	44H013	35L326	35L327	44H010	45L324	
5		45L325	35L329	35L319	35L320	35L332	45L316	
4		45L328	35L333	35L321	35L322	35L330	45L315	
3		45L335		35L331	44H014	45L314	35L012	
2			45L321	45L323			45L334	
1								

MIX-7A1

	A	B	C	D	E	F	G	H
10								
9								
8								
7				45L317	47L035		47L033	
6		47L034	44H010	35L326	35L327	45L318	45L324	
5		45L325	35L329	35L319	35L320	35L332	45L316	
4		45L328	35L333	35L321	35L322	35L330	45L334	
3		45L335		35L312	47L036	47L037	35L331	
2			47L038	45L323			45L336	
1								

H resp. L .... IRT-2M fuel assembly with enrichment 80% resp.36%

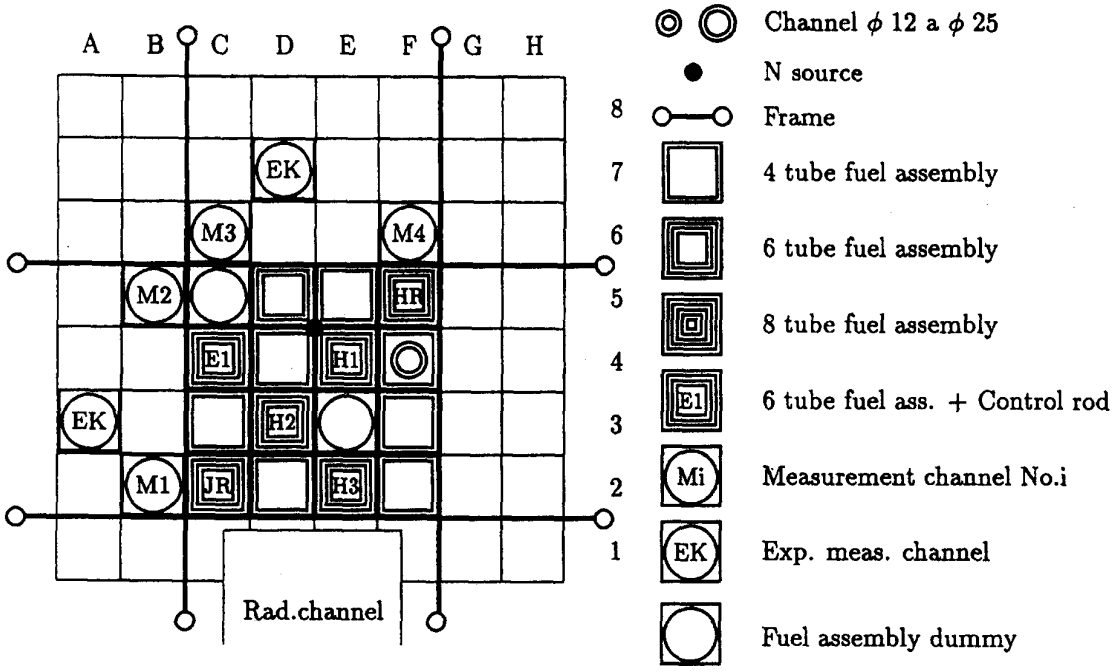
Tab. 1 Overview of Main Characteristics of Mixed Cycles realized on the LVR-15 reactor

Mixed core	DATE	Number of FAs present in core				Average Burnup of all FAs HEU [%w U235] LEU				Reactivity excess [β_{eff}]		Total Power time	Total Oper.time	U235 - Loading [g]	
		TOTAL	HEU	LEU	Fresh	BOC	EOC	BOC	EOC	BOC*	EOC**	[MWd]	[day]	BOC	EOC
1A1	10.06.-03.07.95	31	29	2	2	23.9	30.1	0.0	5.0	9.72	1.73	237.9	23.8	3901	3590
1A2	01.12.-18.12.95	32	30	2	0	30.4	34.0	5.0	8.4	8.42	2.39	142.2	16.8	3699	3514
2A1	20.03.-29.03.96	32	28	4	2	33.2	34.3	4.2	5.2	9.06	6.23	43.4	5.5	3792	3736
2A2	13.05.-25.05.96	32	28	4	0	34.3	36.7	5.2	7.1	8.42	2.57	93.2	11.7	3736	3614
2A3	17.06.-28.06.96	32	28	4	0	36.7	38.7	7.1	8.9	8.12	2.62	81.6	11.2	3614	3508
2A4	09.07.-18.07.96	32	28	4	0	38.7	39.4	8.9	9.5	6.72	2.81	28.5	4.2	3508	3471
3A1	12.09.-22.10.96	32	24	9	5	38.4	43.9	4.2	9.2	8.33	0.42	236.0	25.4	4259	3953
4A1	25.11.-08.12.96	32	20	12	3	42.6	45.4	6.9	9.6	9.15	3.22	122.2	12.9	4310	4151
4B1	15.01.-24.01.97	32	20	12	0	44.8	45.8	9.6	10.6	8.79	3.91	43.6	4.6	4168	4111
4B2	03.03.-07.03.97	32	20	12	0	45.8	46.6	10.6	11.4	8.98	3.83	34.6	3.9	4111	4067
4C1	21.04.-27.04.97	32	17	15	3	45.4	46.5	9.3	10.4	11.06	5.59	52.4	5.8	4483	4416
4C2	09.05.-30.05.97	33	18	15	0	46.1	49.7	10.4	14.2	9.68	2.01	176.8	19.7	4516	4288
4C3	04.06.-14.06.97	32	18	14	0	44.9	46.9	14.5	16.4	8.10	2.46	91.9	9.4	4213	4095
5A1	21.11.-03.12.97	31	7	24	9	36.3	38.3	10.5	12.8	10.34	4.03	113.4	11.4	5352	5207
5A2	11.12.-23.12.97	30	6	24	0	42.7	44.7	12.8	15.1	9.93	4.29	105.5	11.4	5061	4927
5A3	06.01.-18.01.98	29	5	24	0	43.7	45.7	15.1	17.4	11.43	5.39	108.8	12.2	4843	4705
5B1	03.02.-25.02.98	29	5	24	0	45.3	48.0	17.4	20.7	9.82	3.60	149.0	16.7	4708	4519
5C1	10.03.-03.04.98	29	5	24	0	45.5	47.8	20.7	23.3	8.59	3.00	123.3	14.2	4539	4583
5C2	27.04.-29.04.98	29	5	24	0	47.8	48.0	23.3	23.5	7.38	4.41	8.6	1.0	4383	4372
5D1	12.05.-22.05.98	29	5	24	0	46.7	48.3	23.3	25.3	9.82	4.43	89.9	10.1	4376	4262
6A1	19.06.-10.07.98	29	3	26	2	46.7	49.1	23.2	25.7	9.68	3.94	119.9	14.1	4560	4409
6A2	09.07.-10.07.98	31	5	26	0	50.9	51.0	25.7	25.9	9.12	5.34	5.1	1.1	4562	4556
6B1	11.08.-21.08.98	30	6	24	0	49.8	51.3	24.5	26.1	9.18	4.22	77.0	9.6	4378	4281
7A1	10.09.-19.09.98	29	1	28	4	45.9	47.4	22.1	23.6	10.67	5.59	71.3	8.9	4807	4717

* at start of cold reactor

** before shut down of hot reactor

Fig. 4 B1 VR-1 core configuration



It may appear at the first sight that everything is in order about the conversion of Czech reactors and that it is only a question of time and sufficient funds when the conversion will be finished. Only a few operational - physical questions of minor importance remain open. The IRT-3M fuel type has obviously many advantages over the IRT-2M type, but the U235 content seems to be too high with respect to the bum-up values guaranteed by the producer, i.e. the guaranteed bum-up values seem to be too low. Therefore we will be find a way not to discharge the IRT-3M fuel when it is still physically able for use (the same applies to IRT-2M fuel). The LVR-15 cores are quite large, so that effective research and experimental tasks can be carried out, and the fuel management without previous consumption of excess reactivity (i.e. without beryllium reflector being used) would lead to operational and economic losses. Therefore, main interest will be focusing both on fuel management and on consultations with the provider and the supervisory organisations (regulatory body). The same course of action will be taken for the IRT-4M fuel type. It is good news that the Russian provider himself offers this possibility.

/I/ Listik,E. - Matejka,K.: Enrichment reduction programme on research reactor LVR-15 and training reactor VR-l in Czech Republic, Proceedings The I 91h International Meeting on RERTR, October 1996, Seoul, Korea

/2/ Mat6jka,K. - Sklenka,L.: The first critical experiment with a new type of fuel assemblies IRT-3M on the training reactor VR-1, Proceedings The 20'h International Meeting on RERTR, October 1997, Jackson Hole, WY, U.S.A.

Tab. 2 Approaching VR-1 to the critical state (first calculations vs. measurement)

Core configuration B1	Measurement [$]	MCNP Calculation [$]	DIFER Calculation [$]
13 fuel assemblies, rods ↑	-16.52 ± 10%	-15.72 ± 0.19	-14.11
14 fuel assemblies, rods ↓	-13.11 ± 10%	-12.84 ± 0.20	-11.38
14 fuel assemblies, H1 ↑ others ↓	- 9.00 ± 10%	- 8.97 ± 0.20	-7.62
14 fuel assemblies, H1+ H2 ↑ others ↓	- 4.83 ± 10%	- 5.32 ± 0.21	-4.32
14 fuel assemblies, Hl+H2+H3 ↑ others ↓	- 2.78 ± 5% 1	- 2.98 ± 0.15	-2.51

↑ rods up ↓ rods down

Tab. 3 VR-1 control rod worth

Core configuration B1	Measurement [$]	MCNP Calculation [$]	DIEFER Calculation [$]
Scram rod – H1	2.41 ± 5%	2.57 ± 0.21	2.26
Scram rod - H3	1.33 ± 5%	1.40 ± 0.17	1.27
Experimental Rod – E1	1.25 ± 5%	1.31 ± 0.16	1.15
Fine Control Rod – JR	0.81 ± 5%	0.79 ± 0.11	0.78
Coarse Control Rod - HR	0.83 ± 5% 1	0.87 ± 0.12	0.77

Tab. 4 Experimental and theoretical VR-I criticalities comparison

Core configuration B1	Measurement [$]	MCNP calculation [$]
Critical state (El=450, JR=-281, HR=395)	0.000	+0.04 ± 0.09
Critical state (EI=450, JR=680, HR=328)	0.000	-0.09 ± 0.12
Critical state (EI=450, JR=308, HR=680)	0.000	-0.06 ± 0.11
Inner tube IRT-2M in D4 position	+0.37 ± 5%	0.45 0.10
Inner tube IRT-2M in D5 position	+0.06 ± 5%	+0.17 0.08
Beryllium block in C5 position	-1.07 ± 5%	- 1.300.17