THE NEW COMPACT CORE DESIGN OF THE FRG-1

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Abstract

The GKSS research center Geesthacht GmbH operates the MTR-type swimming pool research reactor FRG-1 (5MW) for more than 40 years. The FRG-1 has been converted in February 1991 from HEU (93%) to LEU (20%) in one step and at that time the core size was reduced from 49 to 26 fuel elements. Consequently the thermal neutron flux in beam tube positions could be increased by more than a factor of two /1,2/. It is the strong intention of GKSS to continue the operation of the FRG-1 research reactor for at least an additional 15 years with high availability and utilization. The reactor has been operated during 1998 for more than 280 full power days. To prepare the FRG-1 for an efficient future use, a large set of nuclear calculation have been performed to reduce the core size in a second step from the current 26 fuel elements to 12 fuel elements. To achieve this reduction the fuel loading has to be increased from 3,7 g U/cc to 4,8 g U/cc.

1. INTRODUCTION

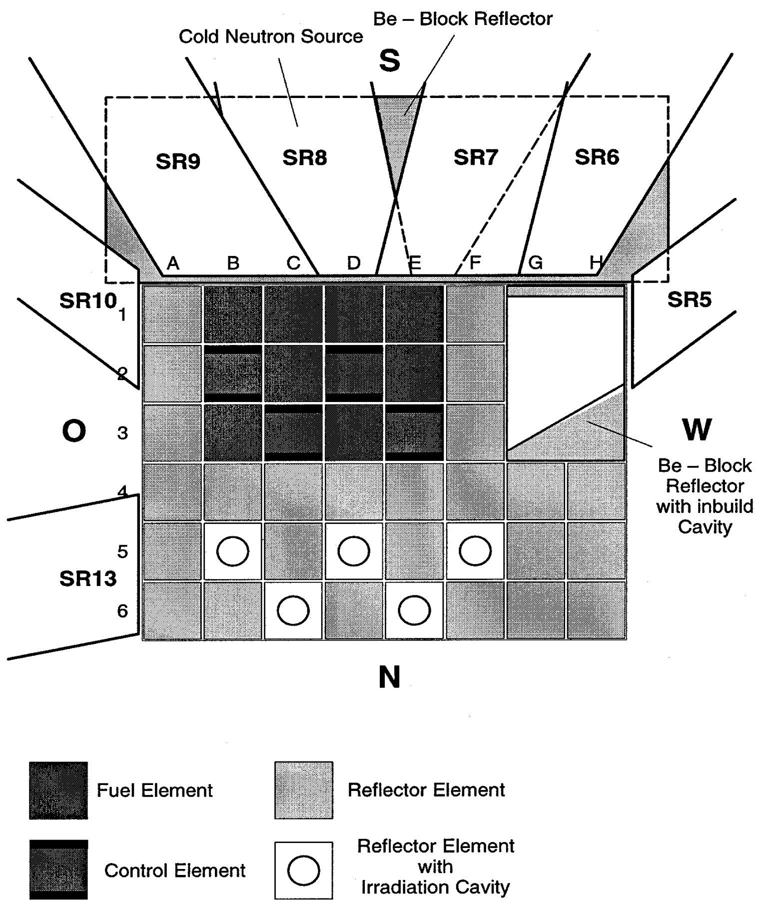
The research reactor FRG-1 has been originally designed and constructed in 1957/1958 (criticality on October 23, 1958) to serve general scientific research needs in different aspects of fundamental research and some applied research like cracking phenomena of organic coolants and isotope production. It is clear that during the lifetime (40 yr) of the research reactor the research areas have been changed more than once. The outcome of such changes results on the one side in new experimental facilities at the beam tubes and on the other side in design changes at the reactor. The following design changes have been made: increase of fuel loading, increase of burnup, reduction of enrichment, reduction of core size, new control rods, installation of a cold neutron source. At present the FRG-1 is being used with high availability for beam tube experiments for fundamental and applied research in biology, materials research, neutron radiography, neutron activation analyses etc.

At the moment we are considering an additional core size reduction by more than a factor of two to increase the thermal neutron flux at the beam tubes by approx. 70 % (see table 1). For this purpose the U-235 density will be increased from 3.7 g U/cc to 4.8 g U/cc. So that finally the size of the reactor is being reduced from 48 fuel elements to 12 fuel elements over the last 10 years. The model for the future core with the beryllium reflector and the beam tubes is shown in Figure1.

TAB. 1. Comparison of present and future core

	present core	future core
Thermal Power (MW)	5	5
Number of fuel elements	26	12
Number of control rods	5	4
Fuel	U_3Si_2	U_3Si_2
U-235 enrichment (%)	19,75	19,75
Fuel density (g U/cc)	3.7	4.8
U-235 content per standard fuel element (g)	323	420
ave. heat flux (W/cm^2)	12	25
Coolant velocity (m/s)	1,6	2,9
Reflector	H_2O,Be	Be
Front end of beam tubes		optimized

FIG 1. Model of the future core with beryllium reflector and beam



2. NEUTRONIC, BURNUP AND ACCIDENT RESULTS

The neutron fluxes were calculated at each beam tube position. The calculational results indicate that the increase in thermal neutron flux for the beam tube is between 50 and 160 % depending on the position of the beam tube. The maximum axial integrated unperturbed thermal neutron flux will be at the position of the cold neutron source, it will be increased from $7.5 \cdot 10^{13}$ to $1.3 \cdot 10^{14}$ n/cm^2 sec. Beam tube 8 with the cold neutron source serves around 65 % of the experiments of all beam tubes of the FRG-1 and is therefore the most important beam tube.

The main results of the depletion calculation for the equilibrium core are shown in table 2. The cycle length was computed to be 70 full power days. The average burnup at BOC is 17.8 % and at EOC is 28.7 %. The average discharged burnups in the standard and control fuel elements are nearly the same and around 37 %. Two standard fuel elements and one control fuel element are foreseen to be replaced per cycle /4/.

TAB. 2. Burnup results for the equilibrium core

10.2 % 18.7 %	0 % 9.7 %	0 % 10.2 %	19.4 % 27.4 %
----- 21.2 % 29.8 % -----	9.7 % 19.4 %	----- 0 % 10.9 % -----	18.6 % 27.0 %
27.4 % 35.0 %	----- 10.9 % 21.1 % -----	27.0 % 35.7 %	----- 29.8 % 37.7 % -----

cycle length: 70 full power days discharge burnup: standard element: 35.7 % control element: 37.7 % core averaged burnup: BOC: 17.8 % EOC: 28.7 %

Selected transients were studied within two broad categories: (1) loss-of-flow transients, and (2) uncontrolled reactivity insertions that may occur during reactor startup. The results of our analysed transients are summerized in the following paragraphs.

• <u>Loss-of-Flow:</u> The peak temperatur reached at the clad surface is 105 °C. This value is than the outset of nuclear boiling. The existing safety margin to the flow instability is 6.0, the necessary safety margin to the flow instability is 1.38.

• <u>Reactivity Insertion:</u> From an initial reactor power of 1 W the peak power reached 7.35 MW before shutdown. The peak temperatur reached at the clad surface is 101 °C. The existent safety margin to the flow instability is 9.1, the necessary safety margin to the flow instability is 1.48.

The constructive modification for the new core facilities (grid plate with shroud and the support for the reactor core) are licensed and already manufactured and will be changed in January 2000.

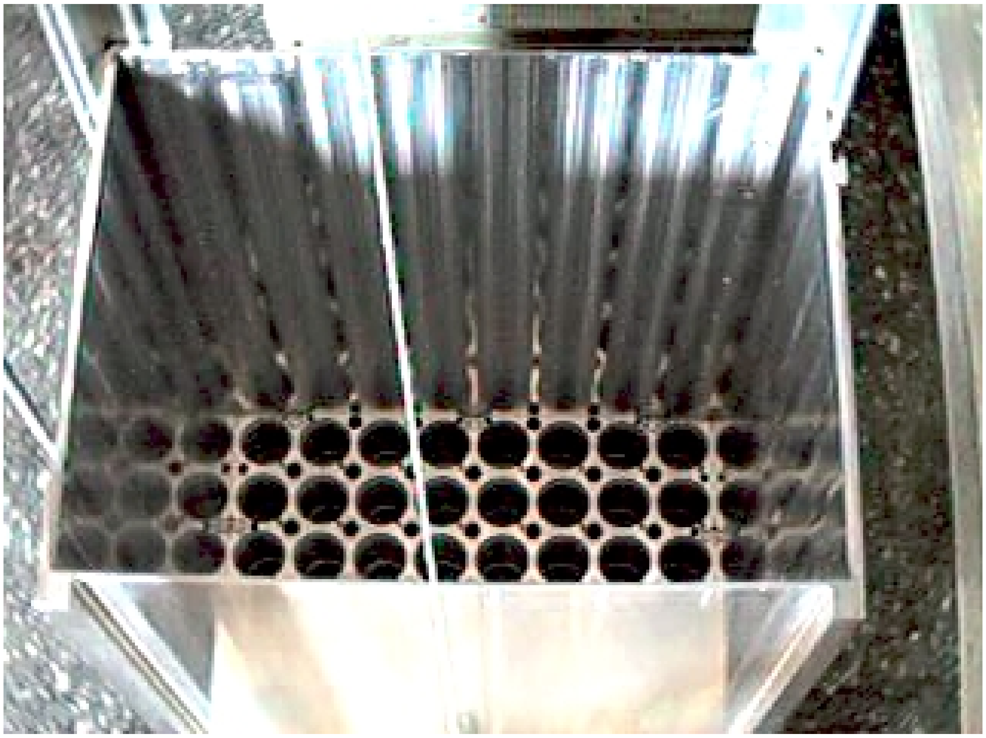


FIG. 2. Grid plate with shroud

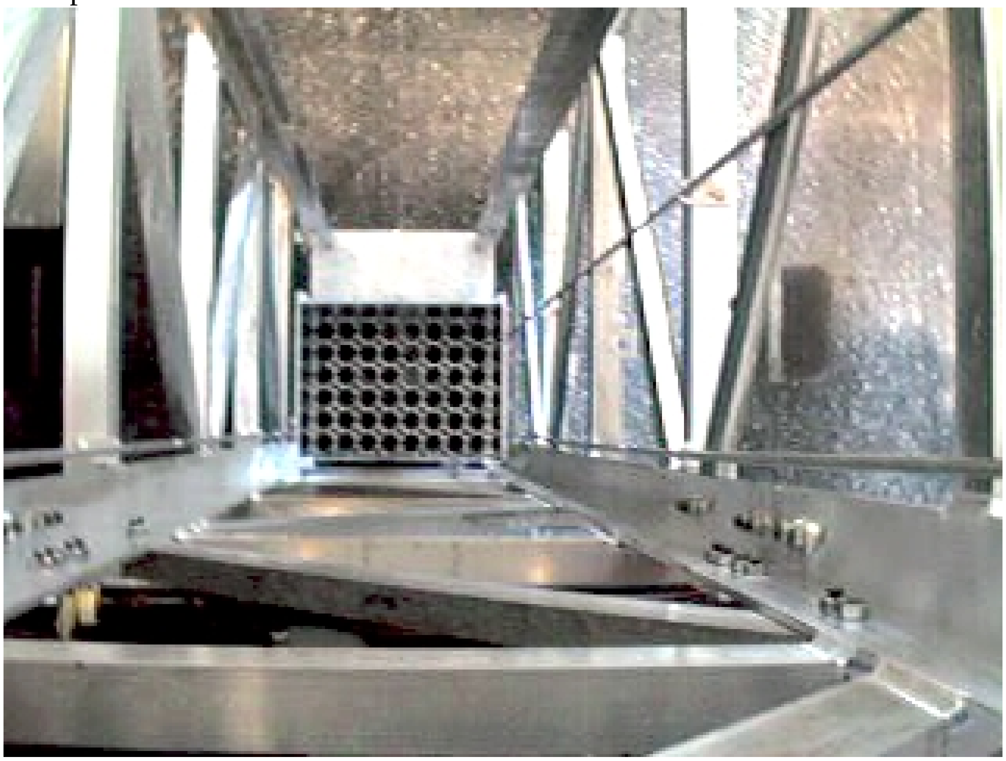


FIG. 3. Grid plate with shroud and support

3. SUMMARY

The constructive modification for the new core facilities (grid plate with shroud and the support for the reactor core) are finished and will be changed in January 2000. The thermohydraulic and safety calculations are finished and the application for the license for the core size reduction is on the way. Comparing this conversion procedure with the first conversion procedure we are hopefully to get a license at the end of 1999.

4. REFERENCES

/1/ W. Krull: Enrichment reduction of the FRG-1 research reactor, International Meeting on Reduced Enrichment for Research and Test Reactors (RERTR), Jakarta, November 4-7, 1991.

/2/ W. Krull and W. Jager: Status and perspectives of FRG-1 after conversion to LEU, International Meeting on Reduced Enrichment for Research and Test Reactors (RERTR), Seoul, October 6-10, 1996.

/3/ P. Schreiner, W. Krull and W. Feltes: Incrersing the neutron flux after reduction of the core size of the FRG-1, International Meeting on Reduced Enrichment for Research and Test Reactors (RERTR), Jackson Hole, Wyoming USA, October 5 - 10, 1997.

/4/ P. Schreiner, W. Krull and W. Feltes: Incrersing the neutron flux at the beam tube position of the FRG-1, Meeting of the International Group on Research Reactor (IGORR 6), Taejon, The Republic of Korea, April 29 - May 1,1998.

Annex

Contribution of research reactors to the neutron research in Germany

1. SIGNIFICANT NUMBERS

In an OECD report published by Prof. D. Richter and T. Springer in November 1998 „A twenty years forward look at neutron scattering facilities in the OECD countries and Russia“, there is stated, that reactors with lower thermal or cold neutron fluxes play an important role in neutron research, too. To consider this in an appropriate way a method has been developed between neutron researchers to be able to compare the research reactors with each other. There has been introduced a „significant number“ K

$$K = Z \bullet G$$

Z = number of experiments at the beam tubes
G = weight factor = $2^{\log \phi}$
ϕ = undisturbed neutron flux in 10^{13} n/cm^{2}sec

For the research reactors used by Germans the relevant numbers are the following

Reactor	power (MW)	criticality	undisturbed thermal neutron flux (10^{13})	G	Z	K
FRM-I	4	1957	5	1,62	7	11
FRG-1	5	1958	8,5 (13)[1]	2,16[1]	12	26
FRJ-2	20 (23)[2]	1962	17	2,35	17	40
BER-2	10	1973	12	2,11	18	38
FRM-II	20	separate	80	3,74	15 (22)[3]	56 (82)
ILL	57	19	120	4,23	11[4]	46

To consider the development of the significant number over the years the proposed shut down for each reactor has to be known:

FRM-I: shut down one year before startup of FRM-II
FRG-1: 2010
FRJ-2: 2005[5]
BER-2: 2015[5]
ILL: 2013[5]

[1] early 2000
[2] since 1995 only 20 MW
[3] 8 till end of 2001, 15 a few years later, 22 after 2008
[4] divided by three = German part
[5] This is presently under discussion

2. AVAILABILITY

The average availability of German research reactors over a 3 years, a 5 years or a 10 years period is in full power day per year:

Reactor	3 years	5 years	10 years
FRM-I	133	126	128
FRG-1	245	231	190
FRJ-2	117	87	72
BER-2	171	192	122

The average availability for the FRM-II is assumed to be three cycle per year = 156 full power days.

3. WEIGHTED SIGNIFICANT NUMBERS

The significant number K of a research reactor does not include the availability of the reactor. As a significant number without availability is only of academic interest for users the availability has to be included in the comparison. Therefore the significant number K must be multiplied with an average of the availability to get a weighted significant number.

Reactor	power (MW)	K	average availability (full power days)	weighted K/ 100	percent
FRG-1	5	26	238	62	24
FRJ-2	20	40	102	41	16
BER-2	10	38	182	69	27
FRM-II	20	56(82)[6]	156	87 (128)	33
				259	100

Conclusion: If the achieved availability is taken into account even small research reactors with low power, high availability lead to an important contribution to neutron research.

[6] numbers taken from the best scenario for FRM-II