REFLECTOR FEEDBACK COEFFICIENT: NEUTRONIC CONSIDERATIONS IN MTR-TYPE RESEARCH REACTORS

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ABSTRACT

Having a negative overall reactivity feedback coefficient is a key safety feature for a Research Reactor (RR). However, such a global parameter can actually be separated into many sub-coefficients, each displaying quite different physical behaviours. The reliable definition of all these contributions depends on the design of the facility, the related Postulated Initiating Events and the safety criteria.
Typically, in the world of RRs, the Reflector Temperature Feedback coefficient (RTF, expressed in pcm per °Celsius) which is defined as the reactivity worth for an increase in temperature of only the reflector (all other temperatures remaining constant), is very often positive in the end. It is also very difficult to measure experimentally and is compensated by other contributions such as the moderator or fuel feedbacks which are strongly negative. This paper discusses the amplitudes and signs of RTFs in the light of neutronics features with some insight from thermal-hydraulics and mechanics. A systematic study is conducted for a fictitious square simple-design RR of various sizes, surrounded by different reflectors: light water, heavy water, beryllium or graphite. It highlights the neutronic insights and illustrates the logic between different existing cores. Different parameters such as the neutron current leakage are analysed to illustrate with simple and robust laws. Results are discussed depending on the physics of all reflectors and cross section effects. Other particular aspects, such as ageing, poisoning or geometrical buckling between inner and outer layers within a given reflector are also assessed.

1. Introduction

When operating a reactor, power or research, having an overall negative reactivity feedback is often a key safety feature. This parameter, sometimes referred to as the Isothermal Temperature Reactivity Coefficient (ITRC) accounts for the reactivity worth of a global increase in temperature within the reactor due to the shift from the cold, zero power state (all temperatures at 20°C for instance) to the hot, full power state with a given spectrum of temperatures for moderator, fuel, cladding, reflector etc.
A negative ITRC ensures a negative feedback in case of a spurious power rise of the reactor. ITRC can be expressed, for instance in reactivity pcm per power percent, or per absolute power MegaWatt (MW), since all temperatures within the reactor are not identical.
However, this ITRC is technically the sum of many different sub-coefficients. Indeed, each material has its own reactivity behaviour due to different temperature dependencies for their respective nuclear data:

- moderator coefficient (both density and cross sections effects in case of a liquid moderator),
- fuel coefficient (due to Doppler broadening of U-238 resonance peaks for instance),
- reflector coefficient,
- other possible coefficients for specific materials,
- sometimes void coefficient (within the moderator) is also a key safety parameter.

This paper deals with the specific Reflector Temperature Feedback coefficient (RTF). It is defined as:

$$RTF = \frac{\Delta\rho}{\Delta T} \quad \text{in pcm/°C} \qquad (1)$$

where $\Delta\rho$ is a reactivity variation of the reactor due to a temperature change ΔT of the reflector only, all other temperatures within the core remaining constant.
We calculate this coefficient for a given Fuel Assembly (FA) design (standard Material Testing Reactor type FA) but for different core sizes and reflector types. The span of the studies is presented in the next section.
The sign of the RTF is discussed. Because of the design of most reactors, this feature has usually no significant impact on safety. The main aspect is that the global ITRC should always remain negative.

2. Presentation of the fictitious cores

Reflector temperature effects will originate from neutronic effectiveness of the reflector itself, with respect to the core. A reflector is usually, but not exclusively, placed outside the FA lattice. If it is not neutronicaly buckled with the core (for instance, if it is too far), physical effects within the reflector will have no impact on the core behaviour and thus on reactivity. Thus, it is intuitive that RTF will be related to neutron leakage between the core and the reflector zones.
Generally speaking, leakage current from a core will depend on its size and the ratio between peripheral FAs and total number of FAs. In this sense, we have studied various sizes for a given core built with a standard MTR-type FA.

2.1 Standard FA model

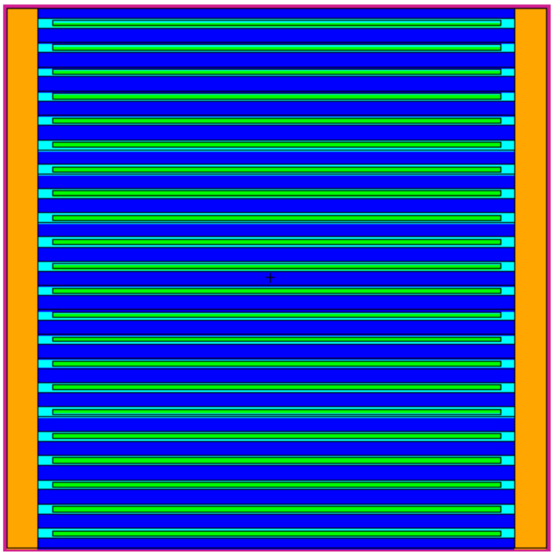

Fig 1 : Standard 22 plate FA

plates	22
fuel height	600 mm
FA square size	82.4 mm
FA and core square pitch	83.4 mm
U5 enrichment	19.75 %
U density	4.8 g/cm3

Tab 1 : FA characteristics

Tab 1 provides design characteristics of the standard 22 plate FA computed in this study to generate various sizes of cores. Fig 1 gives an illustration. Meat is standard LEU U_3Si_2-Al fuel and all structures are modelled as aluminium. FA is square (OSIRIS type) so that the resulting core is also square in order to be as isotropic as possible. In the same logic, adjacent FAs are rotated 90°, as shown in Fig 2 in section **2.3**.

2.2 Reflectors studied

This study focuses on the four most commonly used reflectors:
- Fresh beryllium (Be) with proper water channels
- Fresh graphite (C) with proper water channels
- Pure heavy water (D_2O)
- Pure light water (H_2O)

	Be	Graphite	Heavy water	Light water
height	800 mm	800 mm	1200 mm	800 mm
density	1.85	2.20	1.1086 at 20°C 1.0957 at 50°C	0.9973 at 20°C 0.9880 at 50°C

Tab 2 : Reflector characteristics

Tab 2 summarizes the main characteristics of the reflectors modelled. Except in the case of heavy water, other reflectors are modelled as regular square blocks of the same size as the FAs (8.24*8.24 cm^2) inside the same XY lattice as the core (8.34 cm pitch). All materials are supposed 100% pure in this study. Density effects with temperature are neglected in solid reflectors but are accounted for in water (and studied separately with cross section effects). The simple geometry of the core modelled allows to easily switch from one material to another when dealing with Be, C and H_2O. In these three cases, 1 mm water channels are modelled between FAs and reflector blocks. Also, three rows of reflector are positioned around the core, whatever its size (see Fig 2 in section **2.3**). Reflector blocks are 800 mm high, which means they spread 10 cm above and below fuel axial levels. All the rest is filled with light water.
In the case of heavy water, however, a proper tank is modelled around the core. Its characteristics are given in Tab 3. Heavy water tank material is zircalloy-4. Heavy water spreads 30 cm above and below fuel levels. The geometry of the water tank remains nominal. No thermomechanical effects are taken into account in this generic study.

Tank diameter	260 cm + core size
core - tank water gap	1.5 mm
tank wall thickness	14 mm
tank height	1200 mm

Tab 3 : Heavy water tank nominal characteristics

2.3 Studied cores

Duplicating the FA presented in Fig 1 generates square cores ranging between one single FA and 7x7=49 FAs. As described in the previous section, reflector blocks and FAs are positioned on the same grid pitch (8.34x8.34 cm^2).
Fig 2 gives a view of 1x1 through 7x7 cores with their 3 rows of Be, C or H_2O reflector.
Fig 3 illustrates the particular case of heavy water tanks, modelled as such, with a water gap and a zircalloy-4 wall.

core size	number of FAs	Core geometry: size (cm)	Core geometry: 2D core surface (cm^2)	Core geometry: fuel-reflector interface (cm^2)	D2O tank diameter (cm)
1	1	8.34	69.56	2001.6	268.34
2	4	16.68	278.22	4003.2	276.68
3	9	25.02	626.00	6004.8	285.02
4	16	33.36	1112.89	8006.4	293.36
5	25	41.70	1738.89	10008	301.70
6	36	50.04	2504.00	12009.6	310.04
7	49	58.38	3408.22	14011.2	318.38

Tab 4 : Core characteristics

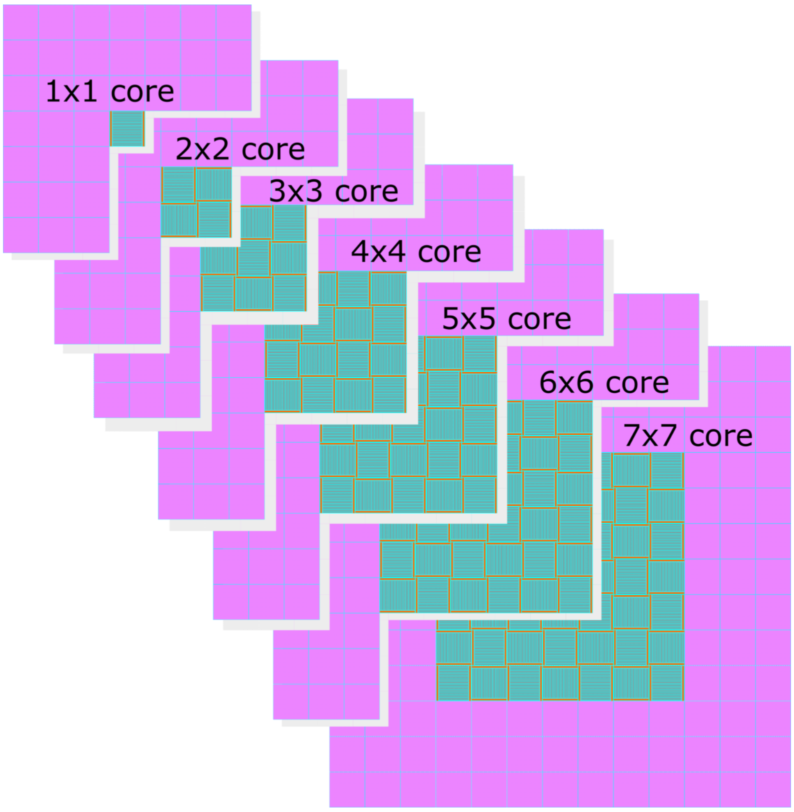

Fig 2 : 1x1 through 7x7 cores, all with 3 rows of reflector

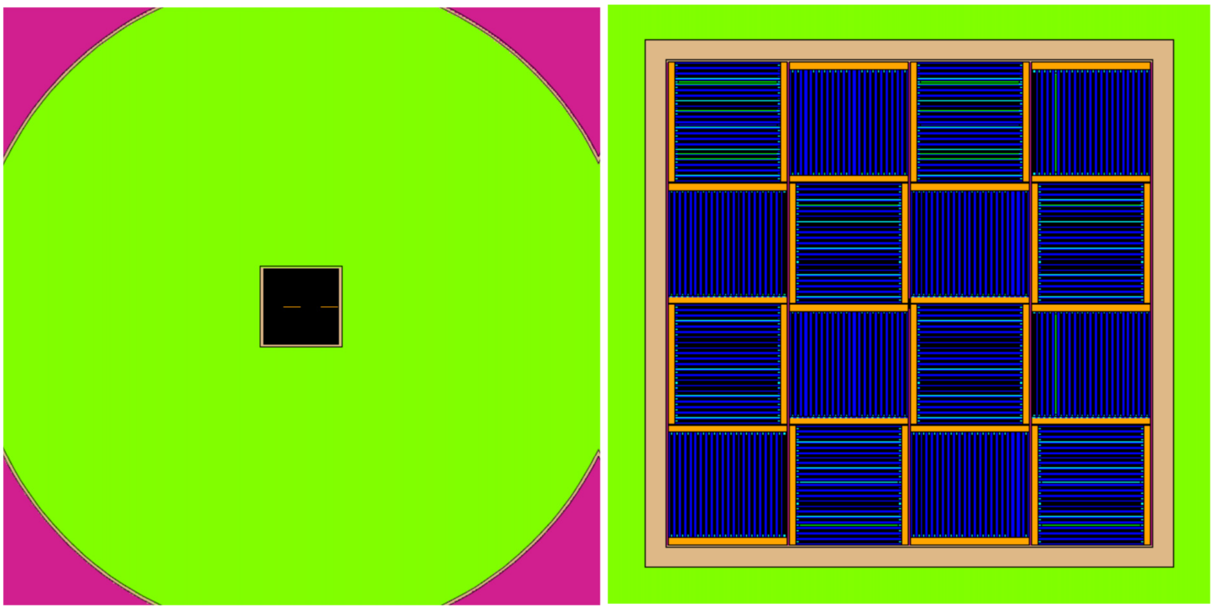
Fig 3 : Heavy water tank in the 4x4 core case (left) with a close-up view of core-tank interface

Finally, Tab 4 provides geometrical data for the different cores modelled: core size and the surface of the fuel-reflector interface integrated over the four sides of the core.

2.4 Codes, data and outputs

All calculations were performed with Monte-Carlo code MCNP6 [1]. Particles were sampled in order to reach a standard deviation of 5 or 6 pcm on the k_{eff} eigenvalue.
Cross sections are all JEFF3.1 at 300K for all materials.
$S(\alpha,\beta)$ correction matrixes are used for reflectors at various temperatures:

- 20°C and 50°C for water
- 400K, 500K and 600K for Be and C

All 7 sizes of cores are modelled in turn with all four reflector types (7*4=28 cases) and in each case, two or three calculations are performed:
- All materials at 20°C
- All materials at 20°C except the reflector:
  - 50°C, density effect only, for water
  - 50°C, density and cross section effects, for water
  - 400K for Be and C

In the 20°C reference case, systematic tallies are performed:
- outgoing and incoming neutron currents on the outer fuel surface (core-reflector interface): tally F1
- average thermal neutron flux in the three reflector rings: tally F4

No power normalization is performed so results are given for one neutron source particle.

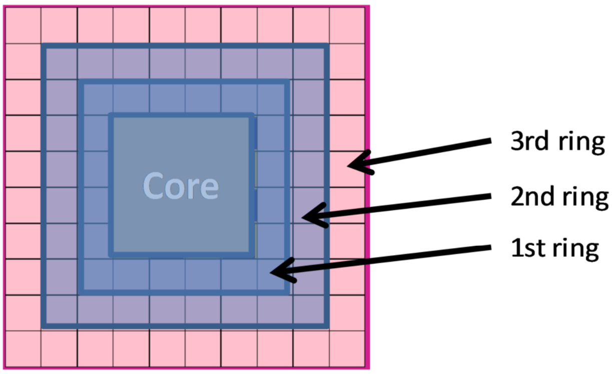

Fig 4 : View of successive integration rings for thermal neutron flux calculation (tally F4)

Fig 4 shows the successive rings of reflector in which thermal neutron flux is averaged. Thermal energies are assumed between 0 and 0.625 eV and flux is integrated between z=+20 cm and z=+40 cm (with z=0 being the bottom fuel plane).
In the case of the heavy water tank, the same geometry is superimposed, resulting in averaged thermal fluxes in successive 8.34 cm thick heavy water rings.

3. Main results

3.1 Reactivity effects: RTF coefficients

General reactivity worth calculations are performed using formula (1) for all the studied cases. Tab 5 summarizes calculated RTFs for all four reflectors and all seven core sizes. All statistical uncertainties are given at 2σ (with a confidence level of 95%).
In the case of water, RTF is separated in two effects:
- density effect at 50°C only, cross section (XS) corrections $S(\alpha,\beta)$ remaining at 20°C
- both density and $S(\alpha,\beta)$ corrections are adjusted at 50°C

RTF values in Tab 5 are consistent with general nuclear physics behaviours. With the exception of H_2O and its largely positive coefficient, all the other common cores in the range of 9 to 49 FAs show RTFs close to 0. Be and C reflector effects are slightly positive and D_2O global effect is slightly negative. This is also the case with the cross section effect on reflector water, largely positive in the case of H_2O and slightly positive for D_2O. However, density effects in water are strongly negative, resulting in all RTFs being negative for D_2O but

the global (density + XS) being positive for H_2O. Values for smaller cores (1-9 FA) give information on the continuity of the phenomena for higher neutron leakage values.
It should be noted that some measurements on D2O tank reactors have shown a positive RTF, thus underlining the difficulty of performing such experiments.

		Beryllium	Graphite	D2O			H2O		
Core size	Number of FAs	RTF (pcm/°C)	RTF (pcm/°C)	RTF (pcm/°C) density only	XS only	density and XS	RTF (pcm/°C) density only	XS only	density and XS
1	1	17.53 ± 0.15	6.41 ± 0.13	-37.44 ± 0.47	6.54 ± 0.47	-30.89 ± 0.47	-17.03 ± 0.43	127.93 ± 0.43	110.90 ± 0.47
2	4	6.64 ± 0.13	2.24 ± 0.15	-11.65 ± 0.57	3.89 ± 0.57	-7.76 ± 0.52	-4.33 ± 0.47	43.09 ± 0.47	38.76 ± 0.47
3	9	3.98 ± 0.15	1.18 ± 0.15	-5.69 ± 0.52	2.20 ± 0.52	-3.49 ± 0.52	-1.35 ± 0.52	20.45 ± 0.52	19.10 ± 0.57
4	**16**	2.71 ± 0.13	0.86 ± 0.13	-3.74 ± 0.47	1.90 ± 0.47	-1.84 ± 0.47	-0.16 ± 0.52	11.18 ± 0.52	11.01 ± 0.57
5	25	1.98 ± 0.13	0.60 ± 0.13	-2.44 ± 0.47	1.23 ± 0.47	-1.21 ± 0.47	-0.42 ± 0.47	7.32 ± 0.47	6.90 ± 0.52
6	36	1.49 ± 0.13	0.43 ± 0.13	-1.89 ± 0.47	0.96 ± 0.47	-0.93 ± 0.47	-0.15 ± 0.47	4.99 ± 0.47	4.84 ± 0.47
7	49	1.24 ± 0.13	0.36 ± 0.13	-1.36 ± 0.47	0.74 ± 0.47	-0.62 ± 0.47	-0.13 ± 0.47	3.28 ± 0.47	3.14 ± 0.47

Tab 5 : RTF values (pcm/°C) calculated for 4 different reflectors and 7 core sizes

It is possible to normalize these values to the chosen “reference” value of the 4x4 core. Normalized RTF values are given in Tab 6.
Fig 5 illustrates these normalized curves. It is clear in that figure as in Tab 6 that, starting at the 3x3 core, all normalized RTF curves are very close, indicating a similar behaviour when all effects (density and cross sections) are taken into account.

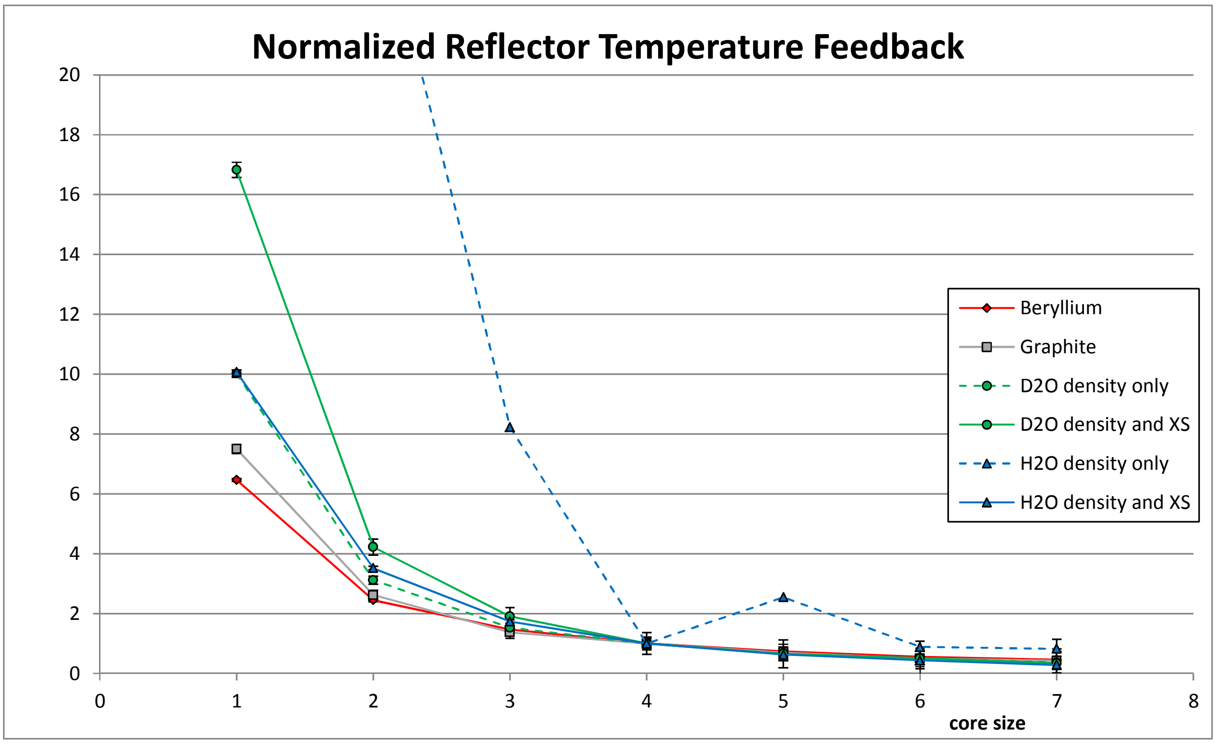

Fig 5 : Normalized RTFs for all four reflector types and all 7 core sizes

		Beryllium	Graphite	D2O		H2O	
Core size	Number of FAs	normalized RTF	normalized RTF	normalized RTF density only	density and XS	normalized RTF density only	density and XS
1	1	6.47 ± 0.05	7.50 ± 0.16	10.02 ± 0.13	16.82 ± 0.26	104.01 ± 3.18	10.07 ± 0.05
2	4	2.45 ± 0.05	2.62 ± 0.17	3.12 ± 0.14	4.22 ± 0.27	26.45 ± 3.18	3.52 ± 0.05
3	9	1.47 ± 0.06	1.37 ± 0.20	1.52 ± 0.16	1.90 ± 0.30	8.23 ± 3.20	1.73 ± 0.06
4	**16**	**1.00 ± 0.07**	**1.00 ± 0.22**	**1.00 ± 0.18**	**1.00 ± 0.36**	**1.00 ± 4.50**	**1.00 ± 0.07**
5	25	0.73 ± 0.08	0.70 ± 0.27	0.65 ± 0.23	0.66 ± 0.47	2.54 ± 3.38	0.63 ± 0.09
6	36	0.55 ± 0.10	0.50 ± 0.35	0.51 ± 0.28	0.51 ± 0.57	0.89 ± 4.55	0.44 ± 0.11
7	49	0.46 ± 0.12	0.42 ± 0.40	0.36 ± 0.37	0.34 ± 0.80	0.82 ± 4.74	0.29 ± 0.16

Tab 6 : Normalized RTF values calculated for 4 different reflectors and 7 core sizes. Reference is chosen to be the 4x4 core.

3.2 Currents and albedo

Core size	Number of FAs	Beryllium current incoming	Beryllium current outgoing	Beryllium ratio i/o	Graphite current incoming	Graphite current outgoing	Graphite ratio i/o	D2O current incoming	D2O current outgoing	D2O ratio i/o	H2O current incoming	H2O current outgoing	H2O ratio i/o
1	1	1.36368	1.87611	0.73	1.21869	1.79895	0.68	1.11223	1.69475	0.66	0.64199	1.34850	0.48
2	4	1.11950	1.41639	0.79	1.03246	1.37459	0.75	0.99021	1.34658	0.74	0.57872	1.08584	0.53
3	9	0.88982	1.09139	0.82	0.82124	1.05276	0.78	0.81733	1.06220	0.77	0.46800	0.84397	0.55
4	16	0.72174	0.87116	0.83	0.66093	0.83053	0.80	0.67462	0.85585	0.79	0.37202	0.65915	0.56
5	25	0.60360	0.72052	0.84	0.54803	0.67932	0.81	0.56691	0.70828	0.80	0.30031	0.52550	0.57
6	36	0.50908	0.60445	0.84	0.46436	0.57116	0.81	0.48284	0.59644	0.81	0.24265	0.42297	0.57
7	49	0.43962	0.51940	0.85	0.39266	0.47990	0.82	0.42095	0.51577	0.82	0.20023	0.34684	0.58

Tab 7 : Calculated currents at the core-reflector interface

Tab 7 displays calculated currents at the core-reflector interface. Values are in neutrons per source neutron. If incoming current is the neutron current returning into the core (J+) and outgoing current is the current leaving the core (J-), then the ratio between the two is known as the albedo effect:

$$Albedo = \frac{J_+}{J_-} \qquad (2)$$

Fig 6 provides an illustration of albedo effects for all these cores. It is consistent with general nuclear physics laws: albedo asymptotically tends towards unity for an infinite core (note: our cores are not axially infinite, hence asymptote is not 1) and water has a poor albedo in comparison to more efficient reflectors, among which Be has the highest albedo.

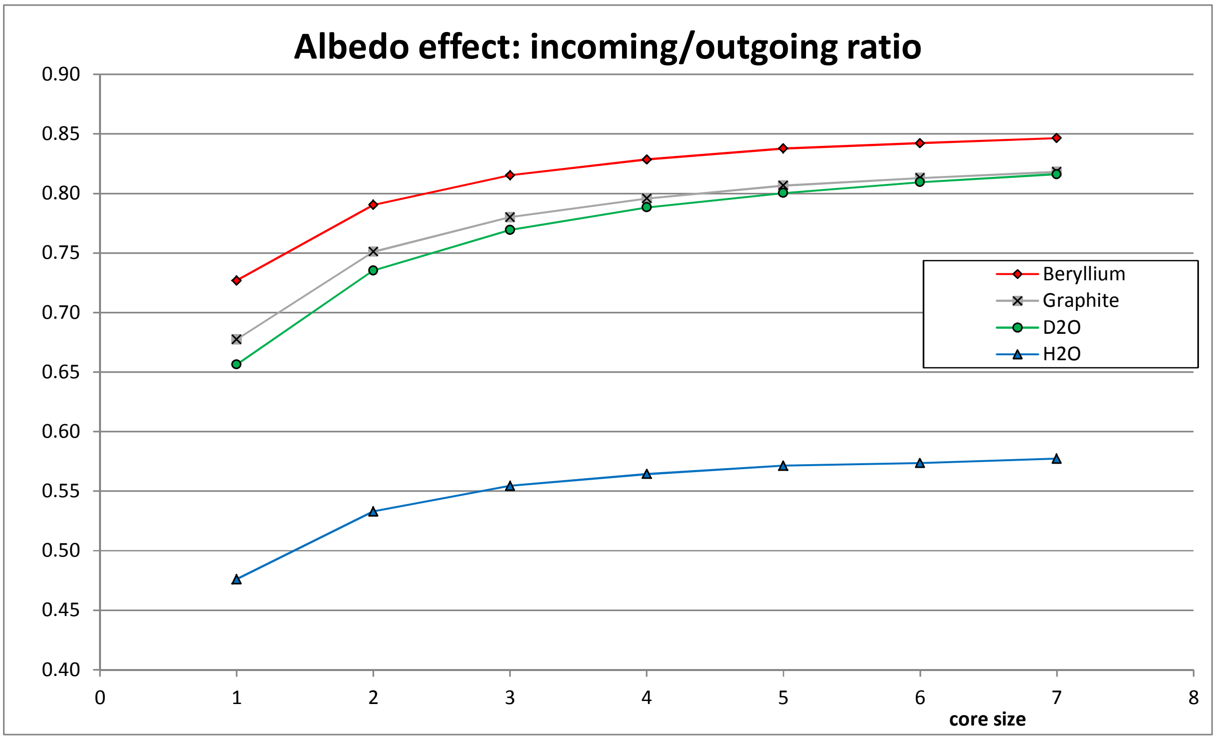

Fig 6 : Albedo effects for all modelled reflectors and core sizes

3.3 Thermal neutron fluxes

Tab 8 provides calculated thermal neutron fluxes in the three successive reflector rings (see Fig 4) and is illustrated, for rings 1 and 2 by Fig 7. Again, general nuclear physics behaviours are observed [2]. Closest to the core, Be and D_2O yield the highest thermal fluxes, but D_2O peak is broader and H_2O fluxes rapidly drop into the reflector.
Since there is no power normalization, fluxes are in neutrons/cm^2 and per source neutron.

Core size	Number of FAs	Beryllium Thermal flux 1st ring	2nd ring	3rd ring	Graphite Thermal flux 1st ring	2nd ring	3rd ring	D2O Thermal flux 1st ring	2nd ring	3rd ring	H2O Thermal flux 1st ring	2nd ring	3rd ring
1	1	1.46E-03	1.08E-03	5.36E-04	1.01E-03	8.53E-04	5.32E-04	1.34E-03	1.27E-03	1.00E-03	8.93E-04	1.77E-04	2.38E-05
2	4	6.28E-04	5.09E-04	2.63E-04	4.48E-04	4.05E-04	2.60E-04	6.30E-04	6.35E-04	5.16E-04	4.34E-04	9.38E-05	1.34E-05
3	9	3.39E-04	2.90E-04	1.54E-04	2.41E-04	2.28E-04	1.50E-04	3.53E-04	3.70E-04	3.07E-04	2.43E-04	5.58E-05	8.32E-06
4	16	2.09E-04	1.85E-04	1.01E-04	1.47E-04	1.43E-04	9.61E-05	2.22E-04	2.38E-04	2.01E-04	1.49E-04	3.58E-05	5.52E-06
5	25	1.40E-04	1.28E-04	7.06E-05	9.78E-05	9.69E-05	6.61E-05	1.50E-04	1.64E-04	1.40E-04	9.73E-05	2.42E-05	3.84E-06
6	36	9.93E-05	9.23E-05	5.19E-05	6.88E-05	6.92E-05	4.79E-05	1.07E-04	1.19E-04	1.03E-04	6.68E-05	1.71E-05	2.77E-06
7	49	7.36E-05	6.95E-05	3.96E-05	5.05E-05	5.15E-05	3.60E-05	7.92E-05	8.90E-05	7.76E-05	4.78E-05	1.25E-05	2.06E-06

Tab 8 : Thermal neutron fluxes calculated in successive reflector rings

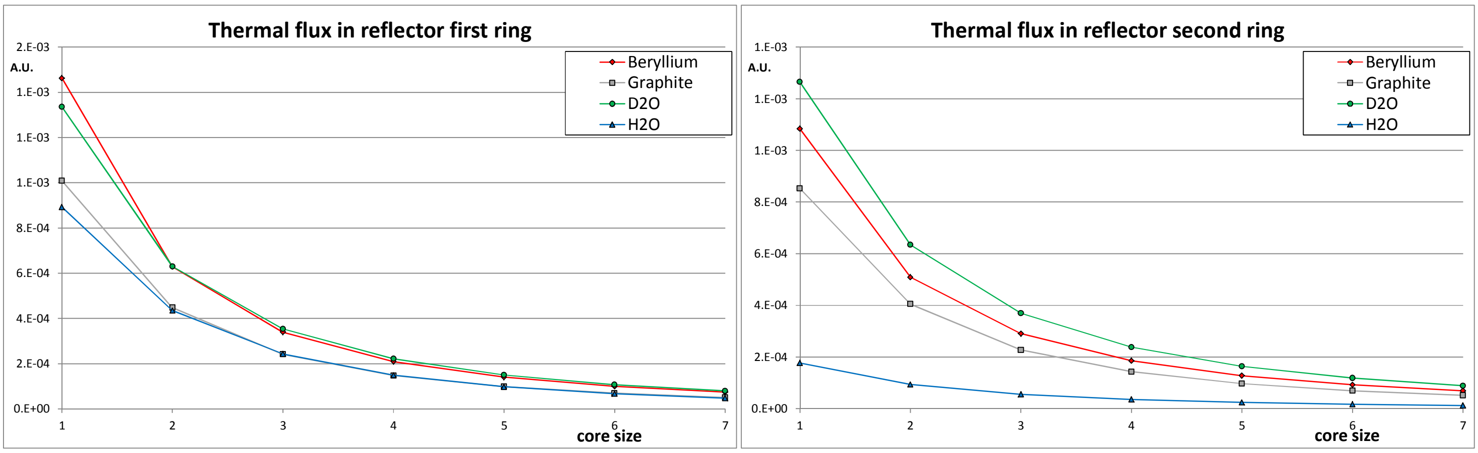

Fig 7 : Thermal neutron fluxes calculated in first and second reflector rings

4. Discussions

It is noticeable that most RTFs are positive (see Tab 5), except in the case of heavy water. Light water and Be positive feedbacks have been reported in the literature [6]. Also, in the case of water (light or heavy), there are two competing effects: an intuitive negative density effect and a positive cross section effect which is discussed below (see also [7]).

However, when positive, this RTF is much smaller in amplitude than the moderator or Doppler coefficients, resulting in an overall negative ITRC for light water moderated reactors. In addition, kinetics of temperature increase within the reflector are both slow (in comparison to faster moderator and Doppler in-core effects) and in some cases guided by a single primary cooling system which prevents the reflector temperature from rising on its own (without the core) and thus resulting in a global negative ITRC. In the case of heavy water tanks, the reactor has a separate cooling system. In this generic study, without any mechanical effect, RTF is negative. Nevertheless, existing D2O tank reactors other than MAPLE have measured positive RTFs. Detailed mechanical studies are necessary in the case of heavy water.

Experimental characterization of RTF is then rather a delicate subject. Section **3** provides orders of magnitude for cores based on a given FA design. One interesting topic turns out to correlate RTF magnitudes, not to the core size, but to other physical parameters that would enable to describe any other core of another FA design. This might be achieved through calculating neutron currents and albedo. Albedo indeed characterizes the reflecting power for a given core.

Fig 8 plots previously calculated RTF values vs albedo effects (see Tab 5 and Tab 7). Behaviours are all almost linear which confirms that, for given physics of a reflector type, RTF is simply correlated to the reflecting power of the material surrounding the core. The stronger the buckling, the stronger reactivity effects are. Plotting normalized RTF (reference being the RTF for 4x4 core) vs albedo yields close and parallel lines (as suggested by Fig 6), but as in Fig 6 and Fig 8, light water is far away from the others. Indeed, light water is a poor reflector due to its strong absorbing power, despite its scattering cross sections being much stronger than for other materials.

Plotting RTFs vs thermal flux in successive reflector rings yields similarly linear behaviours, as suggested in Fig 9. Again, when normalized RTFs are plotted, all four curves are very close, as thermal flux in light water near the core remains strong. But the light water curve rapidly separates from the others if thermal fluxes in the second and third rings are plotted.

Fig 8 and Fig 9 seem to suggest an easy way of assessing amplitude of the RTF for a given reactor, just by knowing its albedo effect, or the thermal flux level within the closest region of the reflector. More detailed studies are generally carried out to assess the RTF during reactor design with more core parameters (burn-up, experimental load…) but such a generic study gives interesting rules of thumb for a preliminary assessment and the management of the knowledge.

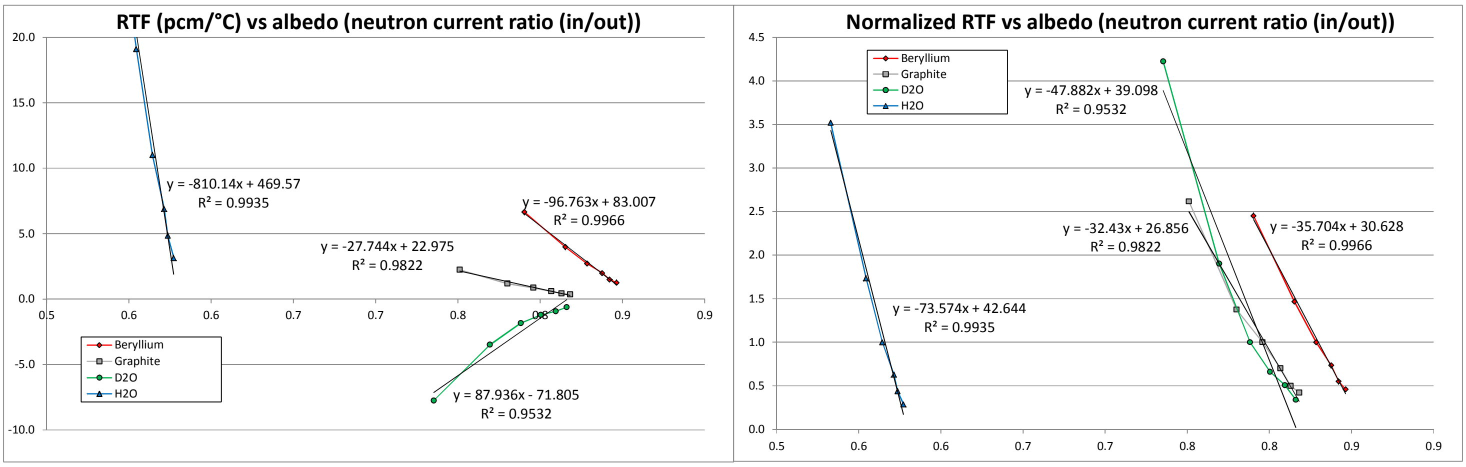

Fig 8 : RTF vs albedo, for different reflectors
(left: absolute RTF, right: RTFs normalized to the 4x4 core value)

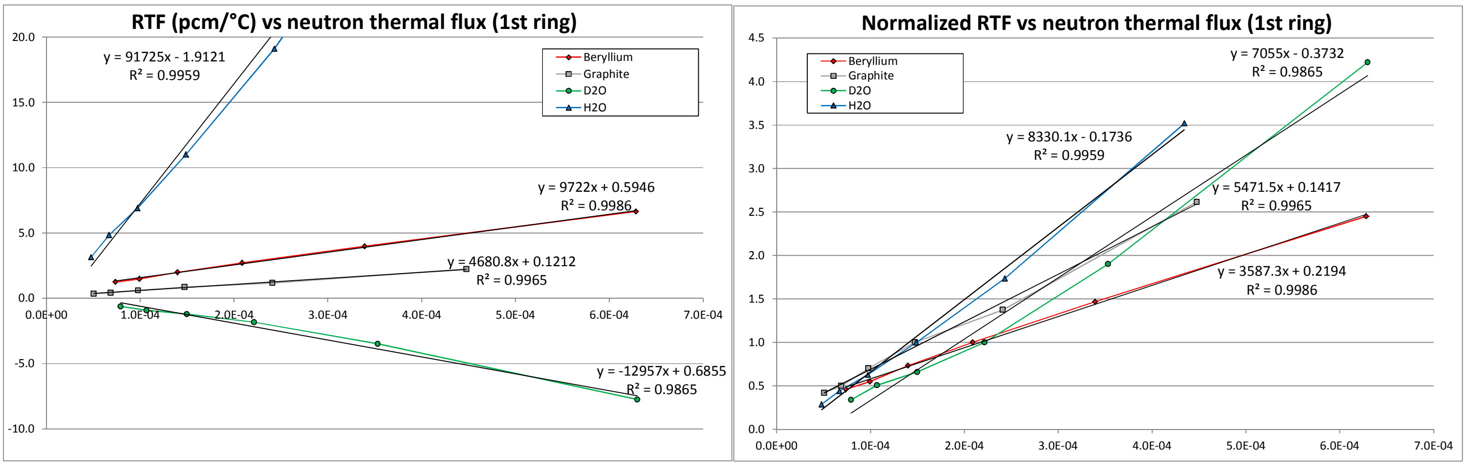

Fig 9 : RTF vs thermal flux in the first ring, for different reflectors
(left: absolute RTF, right: RTFs normalized to the 4x4 core value)

The case of Be provides particular interest since it is widely used throughout the world, despite its positive RTF, and gives high fluxes in the reflector region (even though in a narrower region than D_2O). A few complementary sensitivity calculations are performed in order to assess the stability of the above RTF values. All these calculations are performed on the 4x4 core with a Be reflector.
Be is modelled as 100% pure in this study. Reality is of course different and RTF is calculated with a different material, computing impurities taken into account in the JHR [3], for instance. Absolute reactivity level is indeed affected, but not the RTF, which is a relative

coefficient. In the same field, assessing RTF behaviour with Be ageing (production of Li and He-3) is also very interesting.
A second sensitivity is obtained by modelling a rise to equilibrium of the core at a standard power of 20 MW [4] [5]. Again, absolute reactivity levels are obviously strongly affected, but RTF is relatively stable at +2.7 pcm/°C.
Finally, a third sensitivity is determined, to temperature. Subsequent calculations at 500K and 600K enable to determine a polynomial fit which, if derived, will provide the real law for RTF = f(T), as performed in [7].

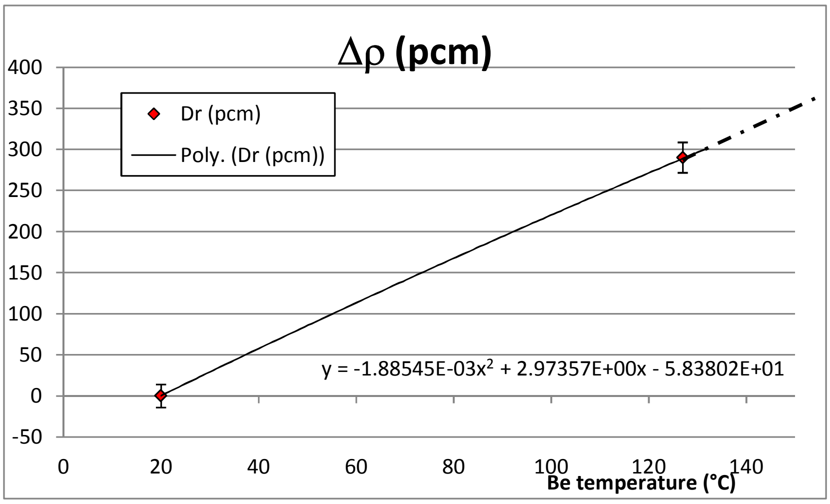

Fig 10 : Reactivity build-up with temperature in the Be reflected 4x4 core
(View is limited to 20-150°C as higher temperatures are irrelevant)

Fig 10 provides this real temperature dependency. Deriving the polynomial fit yields the real RTF value at 20°C which is 2.90 pcm/°C rather than the averaged 2.71 pcm/°C obtained between 20°C and 400K. This is merely the difference between $\frac{\Delta\rho}{\Delta T}$ and $\frac{\partial\rho}{\partial T}$ in equation (1).
This 7% error should not be treated as significant though, since the real safety parameter is the actual reactivity build up between two temperatures and corresponds indeed to the integration of the curve in Fig 10, between 20° and 100°C for instance.

The main physical information resulting from this parametric study is that, with the exception of slightly negative heavy water, RTFs are slightly positive for physical reasons and in particular the cross section behaviours (see Appendix) for the more common range of research reactors.

5. Conclusions

In this study, Reflector Temperature Feedbacks for different reflector types (Be, C, light and heavy water) and different core sizes of a given light-water moderated MTR-type Fuel Assembly are calculated. This illustration is limited to direct neutronic effects, without the indirect thermomechanical effects of reactor structures such as the heavy water tank. Results underline a slightly positive sign for RTFs, due to cross section physics, with the exception of heavy water which remains slightly negative. All RTFs decrease in amplitude with the core size, showing insight for a dependency on neutron leakage.
As regards the impact on the ITRC, first its amplitude is usually small compared to those of moderator and Doppler effects. Second, kinetics of reflector temperature transients are slow compared to those within the core. This ensures an overall negative Isothermal Temperature Reactivity Coefficient in all situations. Finally, a single primary cooling system in many Research Reactors prevents temperature trips in reflector areas without the core also rising in temperature and bringing the proper negative feedback. A positive RTF is therefore not a safety issue.

We correlate RTF with albedo effect and thermal flux in the reflector inner ring, resulting in simple linear trends which highlight the dependency of RTF on the reflecting power of the material positioned around the core. Each operator can use that sort of generic illustration and use the very simple laws established in this paper to compare with his own calculated or experimental measurements, both determined with a methodology close to that used in [7].

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6. References

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Appendix: Additional information about Be cross section

In the case of Be, Fig 11 below plots the JEFF3.1 total cross section (300K) along with thermal corrections S(α,β) at 300K (bena01), 400K (bena02) and 500K (bena03)

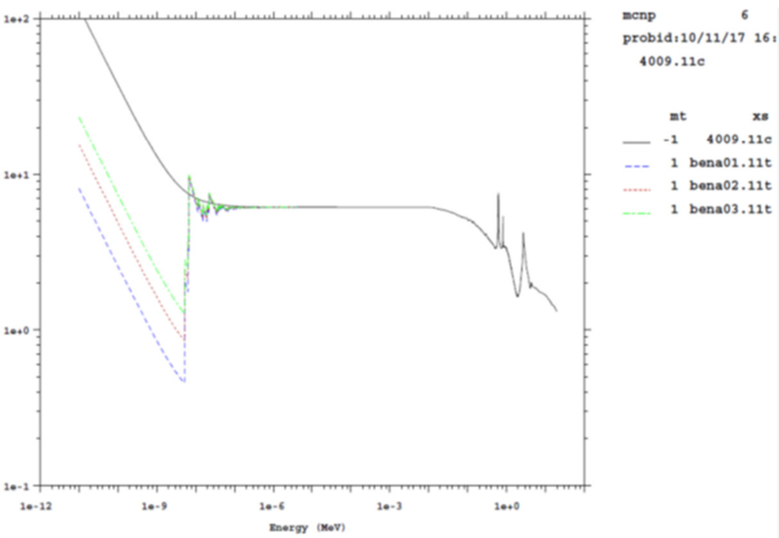

Fig 11 : Be cross sections

A strong correction is visible at low energies, with a cut-off between elastic and inelastic behaviours around 3 meV (or 5 Å). Temperature dependency of the S(α,β) correction is $T^{1/2}$, which is physical. And the effect is positive, resulting in a positive reactivity feedback. Although upscattering is present, it doesn't account for much of the calculated effect.

Also, microscopic cross sections (without S(α,β) corrections) show no visible temperature dependency. Thus, all the results in this study rely on computed models within the S(α,β) corrections. This raises the strong question of the reliability of these data, not only for Be, but also for graphite and water (light or heavy).