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MAGNOX DECOMMISSIONING DIALOGUE

TIMESCALES WORKING GROUP

CHARACTERISTICS OF IRRADIATED GRAPHITE

STORED (WIGNER) ENERGY

CLIENT: THE ENVIRONMENT COUNCIL

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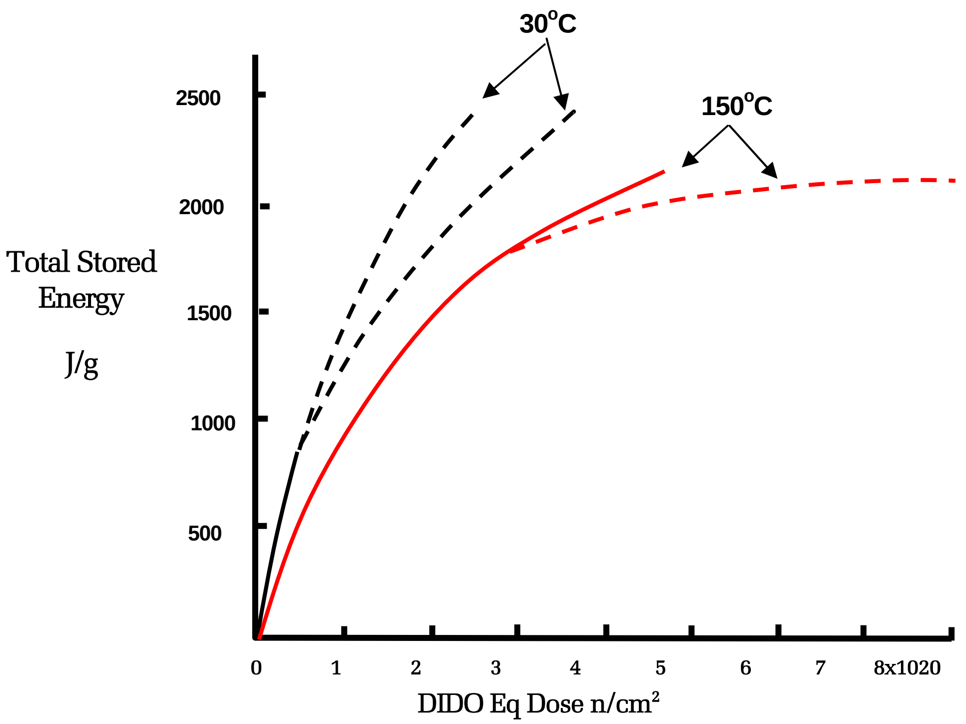
CHARACTERISTICS OF IRRADIATED GRAPHITE – WIGNER ENERGY

The graphite core of the Magnox reactor serves three distinct purposes: First, the graphite moderates or slows down fast neutrons to increase the probability of fission; second the core separates and supports the stacks of fuel elements in channels to maintain overall a critical mass; and third it directs and routes the gas coolant which removes the heat of the fission and radioactive decay processes occurring in the fuel.

The two dominating parameters associated with the ageing of the graphite are the total bombardment of atomic and sub-atomic particles, generally referred to as the neutron dose or irradiation (expressed as neutrons per square centimetre or n/cm^2), and the temperature of irradiation (°C).

For decommissioning the neutron dose is the accumulated neutron irradiation over the entire operational lifetime of the reactor and the irradiation temperature is the temperature at which the moderator core operated whilst in service (see Table 1).

TOTAL ENERGY STORED – WIGNER ENERGY



GRAPH 1 TOTAL STORED ENERGY OF IRRADIATED

Graph 1 shows how i) the maximum total energy stored reduces with the higher the temperature at which irradiation took place, and ii) that the energy storage rate decreases with increasing irradiation. The moderator inlet and outlet temperatures of a Magnox reactor are higher than the 150ºC limit shown in Graph 1, with these temperatures differing for the particular station design. The design condition (pre-derating) inlet/outlet gas temperatures for Bradwell, Sizewell and Wylfa being as follows, although note that the actual graphite temperature would be somewhat higher than the gas temperature:

TABLE 1 REACTOR CORE DESIGN SPECIFICATION FOR TYPICAL MAGNOX POWER PLANTS

PARAMETER	BRADWELL	SIZEWELL A	WYLFA
Excess Reactivity	Temp 1.6% Xe/Sm 1.7%	Temp 1.86% Xe/Sm 2.03%	Temp 1.8% Xe/Sm 2.13%
Max Excess Reactivity	5.3%	5.13%	5.52%
Control Rod Worth	~	6.32%	7.51%
Average Fuel Burn-Up	3000MWd/tU	Average 3,600MWd/tU	Average 3,600MWd/tU
Fuel Load	237 tU	321 tU	595 tU
No of Fuel Channels	2,575	3,784	6,156
No of Fuel Elements	20,600	26,453	49,248
Fuel Cladding Temp	436ºC	452ºC	450ºC
CO2 Int/Outlet Temp	**180/390ºC**	**215/401ºC**	**250/402ºC**
Coolant Mass	~	~	230 t CO_2
Coolant Pressure	9.6/10 b	19 b	27.1/27.6 b
Coolant Mass Flow	2,387 kg/sec	4,470 kg/sec	10,254 kg/sec
Steam Circuit	hp/lp 52/15 b 374ºC 40/77.5 t/hr	Hp/lp 45/~ b 393ºC	hp only 52 b 400ºC
Moderator	**1,200 t Grade A Graphite**	**2,250 t Grade A Graphite**	**3,800 t Grade A Graphite**
RPV Protection	~	18 valves at 840kg/sec relief	11 valves
RPV Design	Working 9 Test 17.7 b	Working 18 Design 20 Test 22.7 b	Working 27.1 Test 34.2
RPV Construction	20.3m dia x 76.2mm thick steel	19.4m dia x 105mm thick steel	29.2m dia 3.3m thick rc

The total stored energy is given by the empirical relationship:-

$$\text{Total stored energy} = 6.25f$$

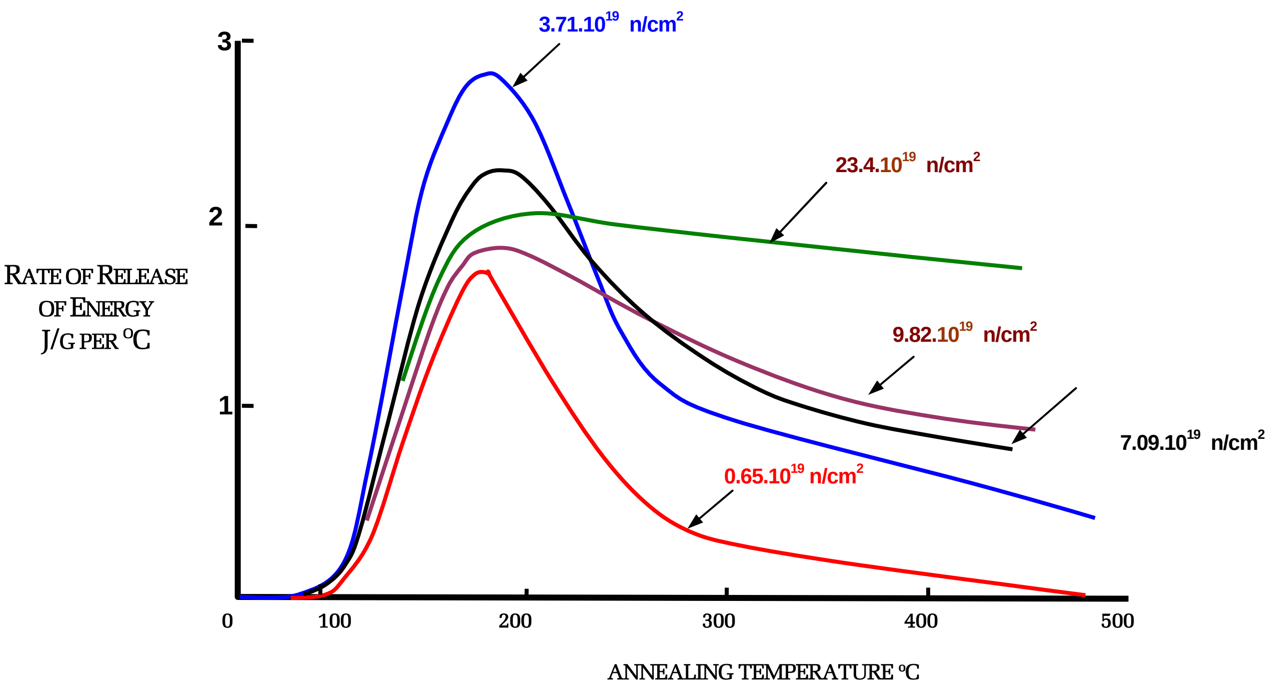
where f is the fractional change of the thermal conductivity of the irradiated to unirradiated graphite at the irradiation temperature. (Ko/K-1) which has a maximum value of stored energy of $2.1.10^3$J/g independent of temperature, with the implication being that the energy takes longer to accumulate at the higher temperature but is, given sufficient neutron dose capable of achieving the same levels. However, some unpublished work (Kelly et al - 1979) claims that above the irradiation temperature of 250ºC the energy stored saturates at lower levels with increasing temperatures and is not significant above 300ºC.

Compared to the total heat of combustion of $3.26.10^4$ J/g the Wigner stored energy represents about (0.21/3.26=) 6% of the total combustion energy available, although depending on air reactivity scenario, the rate of release of Wigner energy might be much higher than the initial stages of combustion.

WIGNER ENERGY RELEASE

The rate of the release of the stored (Wigner) energy varies with the extent of irradiation and temperature. The temperature is usually referred to as the *annealing* temperature because this was the process adopted for releasing the Wigner energy build in low temperature atomic piles, such as the Windscale piles, one of which caught fire in 1957 during a stored energy annealing procedure.

Graph 2 show the energy release for graphite previously irradiated at a constant temperature of 30°C at differing temperatures. The highest rate of release occurs at approximately 180°C for all levels of irradiation, although this *'resonance'* disappears for higher levels of irradiation as shown for the $23.4.10^{19}$n/cm^2 sample.



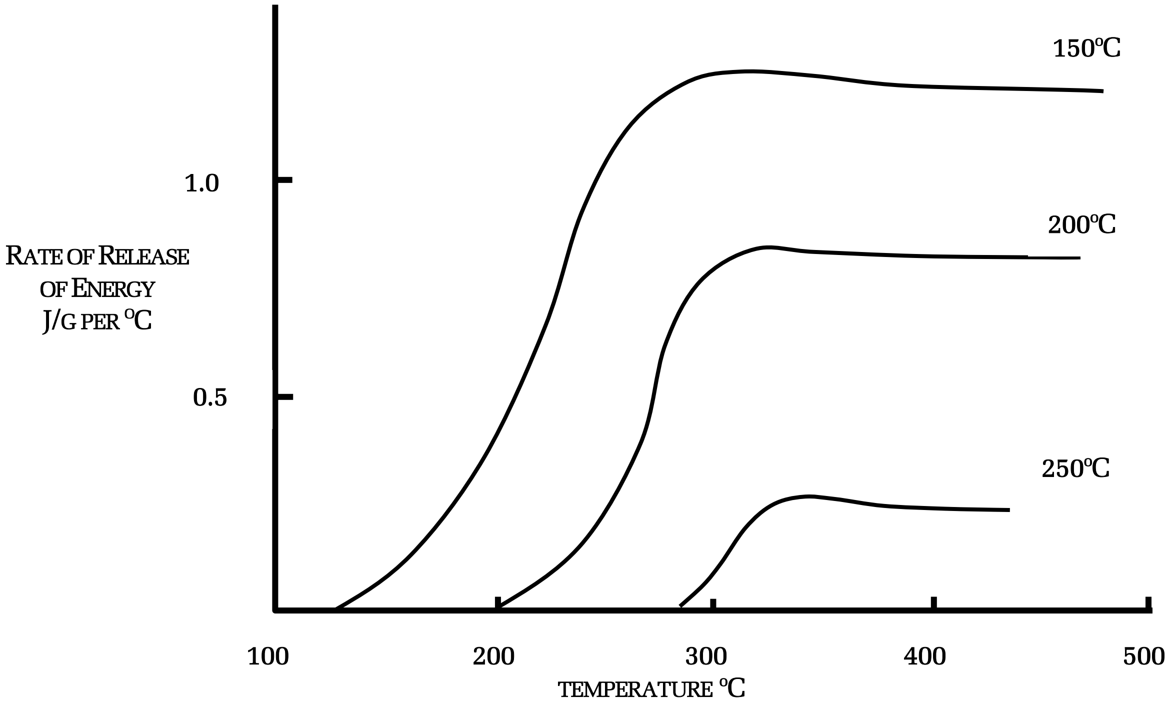
GRAPH 2 RATE OF RELEASE OF STORED ENERGY- IRRADIATED GRAPHITE AT 30OC

Graph 3 shows that the effect of increasing the irradiation temperature is to reduce the rate of release of stored energy with the maximum rate being achieved at a (annealing) temperature approximately 100°C above the irradiation temperature, although this margin decreases sharply above 200°C.

These characteristics can be summarises as the temperature at which the energy release begins increases with increasing temperature of irradiation and the rate of increase of energy storage decreases with increasing temperature.

WIGNER APPLIED TO DECOMMISSIONING

Applied to decommissioning, here we need to consider some event that results in heating of the moderator graphite (this might an external event, such as a some flammable substance being injected into the containment, or an internal event such as chemical reaction). The event has to achieve at least the original temperature of irradiation (about 200°C to 420°C depending on the position within the core) and higher (+~100°C) if the Wigner stored energy release is to be initiated at its peak rate. The amount of the initial heating together with the developing Wigner energy release has to be greater that the moderator's ability to conduct the heat away and dissipate it within the very large thermal mass of the complete core structure, if the Wigner energy release is to be self-sustaining.



GRAPH 3 STORED ENERGY RELEASE AT IRRADIATION TEMP >150°C FOR NEUTRON DOSE 5.10^{20}n/cm^2