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NITROGEN ATMOSPHERE C-14 CALCULATIONS

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NITROGEN ATMOSPHERE C-14 CALCULATIONS

INTRODUCTION

In preparatory work for a nitrogen atmosphere production test, calculations were made of C-14 formation as you have done in HW-57546. Although absolute production rates in HW-57546 and in my previous work are in good agreement for the nitrogen atmosphere case, basepoint assumptions and calculations differ considerably. The purpose of this letter is to point out these differences should they affect radiological engineering judgement regarding the use of nitrogen as a reactor atmosphere.

SUMMARY

The earlier preparatory calculations indicated that total C-14 production (including both the graphite stack and the pile atmosphere as sources) would be increased by a factor of ten to twenty over existing rates, whereas the increase calculated in HW-57546 was less than an order of magnitude. Calculational steps are included under Details.

DETAILS

Consider 1 cc of space in the reactor with a nitrogen atmosphere. The space is approximately 97% filled with graphite having a density of about 1.6 grams per cc. (The other three per cent are voids due to rod and test hole channels, etc.) Since crystalline graphite has a density of 2.25 grams per cc, the stack contains interstitial voids amounting to 30% of the graphite volume. It is assumed that these interstices would be filled with gas. It is further assumed that at a maximum graphite temperature of 600-625°C the volume average graphite and gas temperature would be about 450°C.

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From BNL-325 (second edition) the cross sections for thermal neutron absorption to produce carbon 14 are: $N^{14} \rightarrow 1.75 \times 10^{-24} \text{ cm}^2$, $C^{13} \rightarrow 9 \times 10^{-28} \text{ cm}^2$. The number of atoms per cc are (1): $N \rightarrow 5.3 \cdot 10^{19}$, $C \rightarrow 8.03 \cdot 10^{22}$. The relative isotopic abundances from the Chart of the Nuclides is: N^{14} in N $\rightarrow 0.9963$, C^{13} in C $\rightarrow 0.0111$. Using these values the production of C^{14} per cc is calculated to be:

$$(a) \text{ For } N_2 \text{ gas} \quad (5.3 \cdot 10^{19})(0.9963)(0.3)\left(\frac{273}{273+450}\right)(1.75 \cdot 10^{-24})\phi = 1.1 \cdot 10^{-5}\phi$$

$$(b) \text{ For graphite} \quad (8.03 \cdot 10^{22})(0.0111)(0.97)(9 \cdot 10^{-28})\phi = 7.8 \cdot 10^{-7}\phi$$

The ratio of C^{14} produced in the gas to that produced in the stack is 14.

To obtain actual production rates two further interrelated approximations must be made: the total volume being irradiated and the volume average thermal neutron flux. The graphite stack is about 28 feet by 36 feet by 36 feet. Assuming an effective stack dimension of 26 feet by 32 feet by 32 feet gives a volume of $7.5 \times 10^8 \text{ cc}$. The metal volume average flux in a column operating at 1000 KW is $2.4 \cdot 10^{13}$ (assuming neutrons to be 2200 m/s and neglecting resonance effects). The graphite volume average is about twice this or $5 \cdot 10^{13} \text{ m/cm}^2 \text{ sec}$. In the fringe the average would drop to about $2 \cdot 10^{13}$ so an overall average of $4 \cdot 10^{13}$ should be realistic.

$$(a) \text{ In } N_2 \text{ gas} \quad (4 \cdot 10^{13})(7.5 \cdot 10^8)(1.1 \cdot 10^{-5}) = 3.3 \cdot 10^{17} \text{ atoms } C^{14} \text{ formed/sec.}$$

$$(b) \text{ In graphite stack} \quad (4 \cdot 10^{13})(7.5 \cdot 10^8)(7.8 \cdot 10^{-7}) = 2.3 \cdot 10^{16} \text{ atoms } C^{14} \text{ formed/sec.}$$

For a half-life of 5600 years ($1.77 \cdot 10^{11} \text{ sec}$) the disintegration constant is $3.91 \cdot 10^{-12} \text{ sec}^{-1}$. The curies of radiocarbon generated are:

$$(a) \text{ In } N_2 \text{ gas} \quad \frac{3.3 \cdot 10^{17} \cdot 3.91 \cdot 10^{-12}}{3.7 \cdot 10^{10}} = 3.5 \cdot 10^{-5} \text{ curies/sec. or } \sim 3 \text{ curies/day.}$$

$$(b) \text{ In graphite stack} \quad \frac{2.3 \cdot 10^{16} \cdot 3.91 \cdot 10^{-12}}{3.7 \cdot 10^{10}} = 2.4 \cdot 10^{-6} \text{ curies/sec or } 0.21 \text{ curies/day}$$

Total C^{14} production with He atmosphere 0.21 curies/day.

Total C^{14} production with N_2 atmosphere 3.21 curies/day.

(1) M. V. Davis and D. L. Houser, "Thermal Neutron Data for the Elements" Nucleonics, V. 16, No. 3, March, 1958.

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The C-14 production calculated for a nitrogen atmosphere is approximately the same as you calculated but my calculation of the current production is only about one-tenth of your estimate. Since your conclusions are based on the higher figure, it appears unlikely that any changes are necessitated and that it is safe from a radiological standpoint to run the test.

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