RADIOLOGICAL IMPACT ASSESSMENT FOR NEAR SURFACE DISPOSAL OF $^{232}$Th

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INTRODUCTION

Thorium ($^{232}$Th) itself is not fissile and so is not directly usable in a thermal neutron reactor. However, it is fertile and upon absorbing a neutron will transmute to uranium-233 ($^{233}$U), which is a fissile fuel material. In this regard it is similar to $^{238}$U (which transmutes to $^{239}$Pu). The thorium fuel fabrication may lead to a low level waste comprising of $^{232}$Th. This waste may be disposed of in the Near Surface Disposal Facility (NSDF). The very low probability event of leaching of the waste may lead to contamination of the groundwater system. This paper deals with the estimation of the radiological impact of thorium waste disposal in NSDF through groundwater drinking pathway using the Multiple Area Source Model, MASOM (Sunny et al. [1]). Also, $^{232}$Th has a long decay chain which may lead to the in-situ generation of progeny. The ingrowths of progeny in the NSDF as well as during transport are incorporated using the modified Bateman equation (Eq (1). Codell et al. [2]). The transport model calculates the concentrations of all the $^{232}$Th decay chain radionuclides in groundwater. The modified Bateman equation is then used to calculate the concentrations of all the progeny. The process is complicated by the fact that the progeny will have chemical properties different from the parent radionuclide and will be adsorbed to greater or lesser extent in the solid phase. The concentration of the progeny in the liquid phase must, therefore, be corrected for its distribution coefficient ($K_d$). The concentration of the nth progeny can be calculated as:

$$C_n = \frac{\lambda_n}{\lambda_1} C_1 \left[ \prod_{m=1}^{n-1} \lambda_m \right] \sum_{j=1}^{n} \frac{e^{-\lambda_j t}}{\prod_{k=j}^{n} (\lambda_k - \lambda_j)}$$

(1)

where $C_1$, $\lambda_1$ are the concentration and decay constant of parent radionuclide in the groundwater (Bq m$^{-3}$) and $C_n$, $\lambda_n$ are the concentration and decay constant of the progeny ‘n’. The concentration of the progeny is corrected for the difference in partitioning of parent and progeny between solid and liquid phases by multiplying $C_n$ by ratio of the retardation factors of the parent and progeny. The annual effective dose to members of the public due to consumption of groundwater can be evaluated by the equation (IAEA [3]):

$$D = C \ D_w \ DF_{ing}$$

(2)

where $D$ is the annual effective dose through groundwater drinking pathway (Sv y$^{-1}$), $C$ is the radionuclide concentration in the groundwater (Bq m$^{-3}$), $D_w$ is the drinking water consumption rate (m$^3$ y$^{-1}$) and $DF_{ing}$ is the ingestion dose coefficient of the radionuclide (Sv Bq$^{-1}$).

RESULTS AND DISCUSSIONS

A hypothetical scenario was envisaged 1 Ci (3.7x10$^{10}$ Bq) activity of $^{232}$Th dumped into a NSDF over a period of 50 years (i.e. a total of 50 Ci spread over 50 years). The NSDF is assumed to have an infiltration velocity of 1x10$^{-9}$ m s$^{-1}$. The characteristics of the aquifer are: thickness 12.5 m, groundwater velocity 0.5 m/day, porosity 0.29, longitudinal dispersivity of 1 m and transverse dispersivity of 0.1 m. The distribution coefficients of $^{232}$Th and its progeny for the waste material and the aquifer material along with other nuclear dependent parameters were taken from literature (Sheppard and Thibault [4]; IAEA [5]). Fig. 1 depicts the concentrations of $^{232}$Th and its progeny in groundwater at extremely conservative distance of 100 m from the NSDF. The concentrations are negligible up to 4000 years. After this period, the highest concentration is shown by $^{220}$Rn followed by $^{208}$Tl, $^{212}$Bi, $^{218}$Po, $^{212}$Pb, $^{218}$Ac and followed by $^{226}$Ra and $^{228}$Ra. The parent $^{232}$Th has the least concentration in groundwater. The high concentration of $^{220}$Rn is due to its zero $K_d$ as it is soluble in water under confined conditions. The concentration of $^{220}$Rn is about 38.4 Bq L$^{-1}$ at 100 m distance after 10,000 y of disposal whereas the concentration of $^{232}$Th is about 0.0024 Bq L$^{-1}$. The radionuclide concentrations are translated into annual effective dose to the public through
groundwater drinking pathway (Fig. 2). As the half-lives of $^{220}\text{Rn}$, $^{216}\text{Po}$ and $^{208}\text{Tl}$ are very short, their ingestion dose coefficients are not available at present and hence are considered to be zero.

The highest dose is due to $^{228}\text{Ra}$ ($6.76\times10^{-3}$ mSv y$^{-1}$), followed by $^{224}\text{Ra}$ ($7.45\times10^{-4}$ mSv y$^{-1}$) and then $^{232}\text{Th}$ ($4.4\times10^{-4}$ mSv y$^{-1}$). The total dose has a value of $8.23\times10^{-3}$ mSv y$^{-1}$ at 100 m which occurs after 10000 y of disposal. In this scenario, it can be seen that the parent radionuclide contribute only 5.34 % to the dose and the remaining 94.66 % is contributed by the progeny; $^{228}\text{Ra}$ and $^{224}\text{Ra}$ being the main contributors with higher dose coefficient values and comparatively lower values of $K_d$ as compared to the parent $^{232}\text{Th}$.

CONCLUSIONS

In the present scenario, with disposal of 50 Ci ($1.85\times10^{12}$ Bq) activity of $^{232}\text{Th}$ in NSDF over a period of 50 years, the total dose to the members of the public through groundwater drinking pathway after 10000 y of disposal is $8.23\times10^{-3}$ mSv y$^{-1}$ ($8.23$ µSv/y) at 100 m from the disposal facility. Also, it is concluded that the major contribution to the total dose is of the progeny rather than the parent itself. It signifies the importance of incorporation of in-situ generation of progeny in model formulation and hence the dose due to these.

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REFERENCES