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Natural scientific strategy for nuclear wastes: Philosophy of Dr. Rodney C. Ewing at Stanford

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1. Introduction

As a natural scientist, geologist, Dr. R. Ewing has investigated on the integrity of the long-term nuclear waste repository in which the newly announced South Korean plan for the nuclear waste repository is discussed. The long period should be far more than the sense of humans, because several hundreds of thousands years need to be under control of radioactivity in the waste forms. In fact, it is impossible to know who can see the final stage of the high-level nuclear waste repository when the radioactive level is equivalent to or sublimated by the common level of the nature in this Earth. Therefore the naturally compatible strategy is needed in the high-level nuclear waste treatments.

In the geological study, the naturally adapted region was discovered in Oklo, a central African area of Gabon seen in Fig. 1. Currently, this naturally operated nuclear fission site has been stabilized where the artificial shielding structure was not equipped. So, it has been studied to be an exemplified high-level nuclear waste repository. This could give a lesson that one should make the nuclear repository construction. In Fig. 1, the simplified configuration of the Oklo natural nuclear reactor site is described [1]. The natural reactor was in the critical state of U-235 and groundwater was considered as the moderators. Dr. Ewing mentioned for the geological waste treatment as follows [2],

"We must rely on our understanding of natural processes that operate on geologic time scales in order to predict the future behavior of a nuclear waste repository"

in which the natural process in the repository was emphasized such like the Oklo case. Since the human life span is nearly just around one century, the geological time scale means the term beyond human's control. In Fig. 2, the time scale comparison is shown. It is thinkable of the basic question in Fig. 3. Considering stochastic prediction, there are the very severe limitations of the nuclear waste managements. He said [3],

"The limitations of probabilistic performance assessment (PPA) are especially important when it is applied to natural systems for which there is a sensitive dependence of the final result on initial or bounding conditions"

where the deterministic calculations were utilized in the very long period of natural geological time line. In the historical review, there are two tables for the South Korean nuclear repository in Table I and II [4]

2. Methods and Results

The integrity of the waste form has been studied in this study for the natural adaptations. There are four kinds of materials for this study; Sheet Silicate (Mica) compositions, Zeolite compositions, Smectite compositions, and Crystalline Silicotitanate, which had been studied by Dr. Ewing [5-9]. The alpha particle is injected ion in the simulation [5]. For 'amorphization', simulations are done as 10,000 ions which are injected into four targets [6-9]. It is suggested to calculate following equation for the susceptibility [10]. The number of displacements per atom of the target is [11-13],

$$\text{dpa} = (1 \times 10^{-16}) N_d \cdot D_c / \rho_n \tag{2.1}$$

where,
N_d: Target displacement (displacement/ion/Å)
D_c: Critical dose (ions/cm^2)
ρ_n: Atomic density of the target material (atoms/Å^3)

This equation is used for the calculation of D_c (critical dose, ions/cm^2). It is also used for finding the susceptibility of the waste form. Additionally, for the radiation protection in the health physics, it is needed to find the dose equivalent in (2.2).

$$\begin{aligned} \text{Energy absorbed/s} &= 3.7 \times 10^4 C(t)\bar{E}\ MeV/s \\ &= 5.92 \times 10^{-2} C(t)\bar{E}\ erg/s \\ &= \frac{5.92 \times 10^{-2} C(t)\bar{E}}{M} erg/g \cdot s \\ &= \frac{5.92 \times 10^{-2} C(t)\bar{E}}{M} rad/s \\ &= \frac{5.92 \times 10^{-2} C(t)\bar{E}Q}{M} rem/s \end{aligned} \tag{2.2}$$

where, the $C(t)$ is a critical dose in μCi, which is from the ion numbers of an unit of ions/cm^2. $\bar{E}$ is 20 keV as an average energy. Q is a quality factor as 20 for alpha particle. The mass is 100 kg.

For comparing an experiment, the SRIM 2008 code is used for the simulations [14-16]. This program code is used for calculating the stopping and range of ions from 10 eV to 2 GeV/amu in the quantum mechanical matters including solid and liquid states for the ion-atom collisions. In Fig. 3, there are Z-axis view and collision events of He+2 ion injection for ZrO_2. The critical dose and dose equivalent rate are shown for four examples. $Ca_5(PO_4)_3F$ has the lowest value and ZrO_2 has the highest one in Table III,.

3. Conclusions

The important mentions of Dr. Ewing reflected his philosophy in geological repository and there is a biography [17, 18]. It is necessary to understand the very big difference between human's cognitive timescale and geological timescale where it could be nearly impossible to construct the long-term or even permanent nuclear waste repository. It is important to understand the opposite opinions of the nuclear waste repository. The government made the milestone of the South Korean repository policy in which the final repository completion was decided as 2053, about 40 years later. Until the time, there is enough time to rethink for the long-term waste repository. It is certain the policy-maker of this nuclear waste policy will be out of the nuclear community before 2053. This means the politician will not take any responsibility of the result of this policy. It is considerable to make new technology to treat the high level nuclear waste until that time. Following the national policy, it is reasonable to think again the many kinds of possibilities using the highly advanced technology like the nano-scale technology incorporated with the information technology where the convergence promotions are important strategies for searching for the best nuclear repository.

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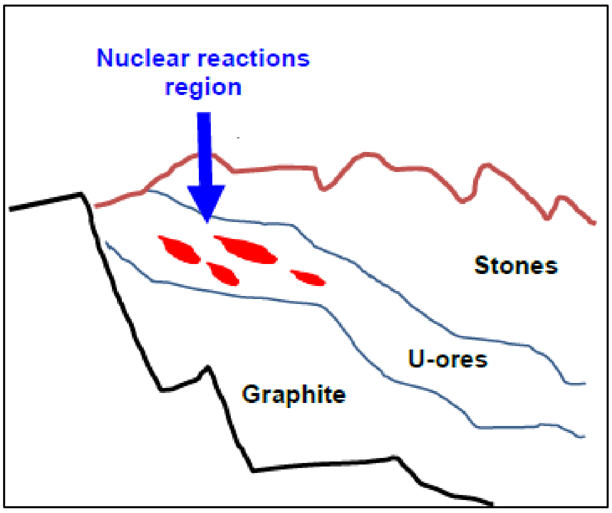
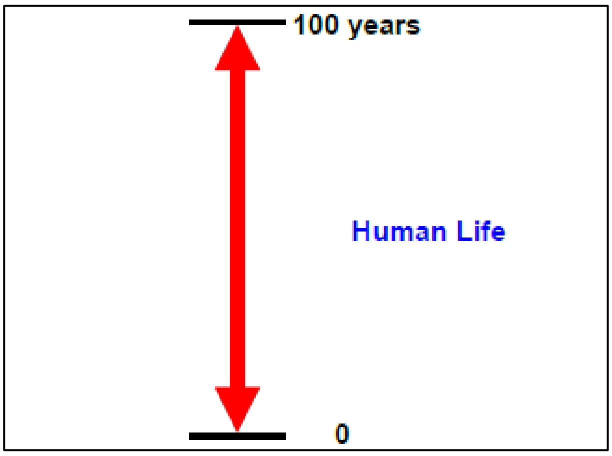
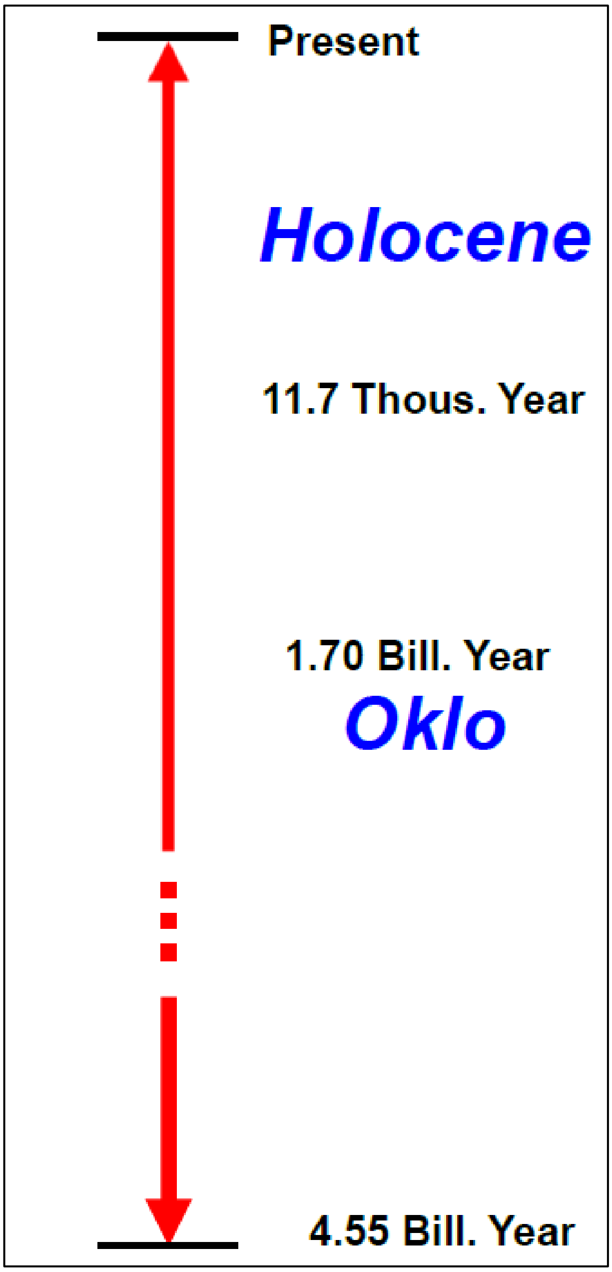


Figure 1. Configuration of nuclear reactions site.



(a)

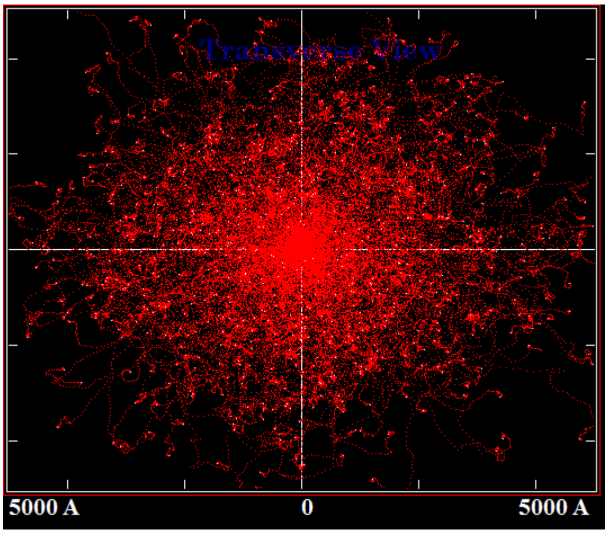


(b)

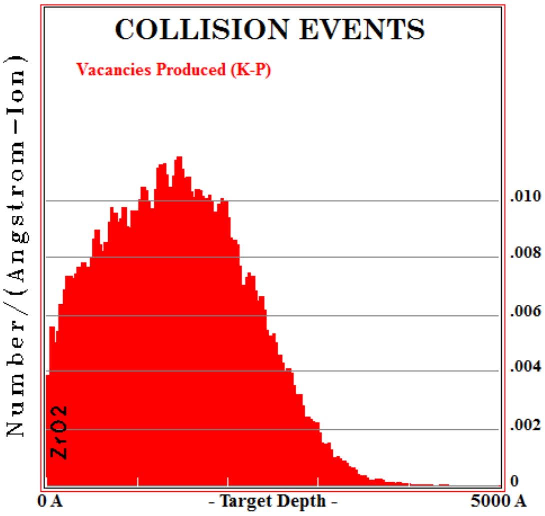
Figure 2. Time scale of change (a) Human life and (b) Geological period.

How to control the mismatch of time scale?

Figure 3. Basic question of geological repository.



(a)



(b)

Figure 4. He+2 ion injection for ZrO_2 (a) Z-axis view and (b) Collision events.

Table I. Nuclear repository construction milestone of South Korea

Year	Policy
~ 2024	Site application
~ 2028	Site Investigations
~ 2032	Research facility construction
~ 2035	Interim repository construction
~ 2053	Permanent repository construction

Table II. History of South Korean Nuclear repository policy

Year	Policy
1991	Chungchung Anmyun-do repository (failed)
1995	Incheon Gulup-do repository (failed)
2004	Buan Yui-do repository (failed)
2015	Mid-low level waste repository in Kyungju (finished)

Table III. Critical dose (× Avogadro number)

Composition	Critical dose(ions/cm^2) : D_c	Dose equivalent rate (rem/sec) : $\dot{H}$
ZrO_2	2.1098×10^{-4}	1.3503×10^{-15}
$CaZrO_3$	1.3752×10^{-4}	8.8000×10^{-16}
ZrSi	1.7630×10^{-4}	1.1283×10^{-15}
$Ca_5(PO_4)_3F$	3.7503×10^{-5}	2.4002×10^{-16}

Table IV. Biography of Dr. Rodney C. Ewing

Year	Policy
1946	Born at Abilene, Texas
1974	Ph.D., Stanford Univ., Mineralogy
1972	M.S., Stanford Univ., Mineralogy
1968	B.S., Texas Christian Univ., Geology
1974	Prof., Univ. of New Mexico, Geology
1997	Prof., Univ. of Michigan, Nuclear Eng. & Radiological Sci., Earth & Environmental Sci., Materials Sci. & Eng.
2014 ~	Prof., Stanford Univ., Geological & Environmental Sciences