Study on the irradiation effect towards water filtration element

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Abstract. Gamma and neutron irradiation effect on material had been studied intensively. It was proved that there are strong correlation between neutron fluence and physical and mechanical damage of materials. The paper is part of the project to study the use of neutron and gamma irradiation to increase the effectiveness of simple water filtration element which are mostly sands and paper or pulp. Studies on irradiation effect on these element are compiled and analyze its changes from atomic structure to physical properties. On the atomic level, the change in atomic structure are relatively similar to the effect of irradiation on any solid, but with slight difference due to different in material composition and grain structure. Change in chemical properties might be less prominent but the change in grain size and its ability to filter water may be different. List of publication on previous experiments conducted on irradiating filtering element are compiled to provide basic idea on the parameters needed to provide significant changes. As a conclusion, the paper provides a preliminary correlation between the fluence and energy level of irradiation with the physical effects towards these filtration element, hence will be used to analyze events leads to change in filtering effectiveness upon irradiation.

1. Introduction
Fundamentally, ionising radiations such as neutron and gamma can affect the properties through interaction with matter such as silica and paper. These two materials are the main components to be studied in this paper. Filtration system in this study uses sand and paper to filter water for domestic users. Interaction of sand and paper with neutron and gamma will affect the porosity of silica and paper due to chemical changes of these two materials after irradiation with neutron and gamma. Flow rate, heavy metals, nutrients in water and colour after filtration would be affected when irradiated materials such as sand and paper were use in filtration system. In this paper literature review were undertaken to study levels of radiation and its effect on chemical properties of sand, paper and water. Most significant changes due to irradiation occurs in high density fluence around structural material of Silicon dioxide, SiO\textsubscript{2} showing radiation damage processes in
structures, including negative charge (electron) to the oxide and consequently reduce the positive charge trapping after irradiation with neutron as shown in figure 1.

![Figure 1. Oxide changes in silicon dioxide (MOS) showing radiation damage in the structure after exposure to neutrons [14].](image)

Neutron and gamma are the ionization radiation that could modify the atomic structure of material if the material expose in a significant time. The change of atomic structure would tend to have a permanent defect on the material. Neutron is neutral in electrical charge and can pass through electron clouds and interact directly with the nucleus while gamma have high energy in form of electromagnetic radiation can ionise the atom. Previous studies had been done intensively on steels and alloys while not many were done on sand and paper. The damage events would likely to be similar with other materials since the basic interaction of radiation towards a material in an atomic level would be similar.

In this paper, the study will look into the effect of radiation of neutron and gamma towards basic water filtration element, which are mainly sand and papers or pulp, especially on the mechanism and damage events that lead to the changes in microstructure of filtering element, hence, changes the ability of these element to function to purify water.

2. The radiation damage event
A primary knock-on atom (PKA), is a displacement of the atom from its lattice site cause by radiation, and further on creates additional knock-on atom until eventually a cascade of displaced atoms are created. The PKA would stop at an interstitial location. Comparing with the atomic structure of sand, which is mostly Silicon Oxide (SiO₂), the effect of radiation are similar to effect on any other solids as shown in figure 2. The radiation damage event is the transfer of energy from the radiation toward the solid target where it consists of a few processes, starting from interaction of radiation with an atom in the lattice atom of the atoms in the sand and paper.
2.1. Effect of Fast Neutron Radiation
High energy of neutron or fast neutron (generally between 0.5MeV and 20 MeV) can disturb the arrangement of atom and crystalline structure of materials. During an exposure of material with fast energy neutron, the structure of material may damage and cause temporary localized. The structural damage more significant for metals because of their relative immunity to damage by ionizing radiation.

2.2.2. Effect of Thermal Neutron Radiation. Thermal neutron have less important effect on the structural damage as they can be captured by nuclei of the irradiated material, which will become radioactive. Normally, after the neutron captured by the nucleus, the nucleus is in an excited or high energy state and excess energy is released by emitting high energy gamma rays, resulting the emitting nucleus recoils and is displaced.

2.2.3. Effect of Gamma on Material. Gamma rays are high energy photon produced from the decay of unstable nucleus. The energy of gamma rays may achieve from a few keV to several MeV. There were three ways of interaction between matter which are photoelectric effect, pair production and the Compton effect. Unlike fast neutron, the probability of an atom being displaced by a direct interaction between gamma rays and atomic nuclei in crystal is very small.

3. Discussion on the other paper
Above explanation proved that interaction of ionization radiation have a significant contribution on the defect of material depends on the energy it have. In this chapter will discuss the previous study that relates to the irradiation of gamma ray and neutron with the elements that use in simple water filtration. The main factor that will be discussed are the neutron fluence and gamma dose rate on the structure of material. Table 1 below shows a few recent study on the effect of irradiation towards the material.
Different doses of gamma rays on the physio-mechanical properties of polymer modified white sand cement mortar.

High gamma-irradiation doses on natural quartz crystals by ESR technique Ordinary Portland cement with 5% of active rice husk ash (RHA) are impregnated with unsaturated polyester resin (UPE) followed by gamma rays ranging from 10 to 50 kGy

Concentration of E'-type defects and oxygen-related defects produced in KU1 samples irradiated with high neutron fluences

Relevence of the manufacturing process (defects and impurities) present in the material before irradiation.

Radiation induced defects and their differences observed in various kinds of epitaxial silicon material Defect parameters on high resistivity silicon with different concentrations of the impurities oxygen and carbon irradiated with neutrons and charged particles.

Effect of gamma exposure dose on the physico-chemical and mechanical properties of polymer-alite composit. Gamma-ray irradiation on water-rock reactions are investigated by comparing leaching experiments with and without irradiation

High-energy radiation towards silica-core optical fiber

Defect of E' centers by irradiation of gamma. Filtration properties of four different filter papers on basis of the results of fibers swelling determination

Gamma irradiation of the filter paper induces the swelling restrictions of cellulose fibers, with progressive effect on prolongation of gamma-irradiation.

Based on the related literatures compiled in table 1, the materials could be categorized into three groups which are Polymer, papers and silicon. Table 1 shows the effect of neutron and gamma fluence on various types of samples with constituents related to sand and paper. Irradiation of gamma on Quartz (SiO₂) between 50kGy to 300 kGy does not change the quartz structure but irradiation of neutron with 10^{22}n/m² or 12MGy on KU1 silica sand causes highest concentration of defect. The optimum range of energy that needed for neutron to have its effect with material is between 10^{21}n/m² and 10^{22}n/m² neutron fluence meanwhile for gamma is 12MGy doses. Irradiation of gamma on paper using 50 to 300kGy causes induces the swelling restrictions of cellulose fibers, with progressive effect on prolongation of gamma-irradiation.

**Table 1. Fluence and effect of neutron and gamma radiation on various sample.**

| No | Fluence     | Sample                          | Radiation effect                                                                 | Outcome Measure                                                                 |
|----|-------------|---------------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| 1  | 10 to 50 kGy | Styrene Acrylic Esther (SAE) cement mortar | Different doses of gamma rays on the physio-mechanical properties of polymer modified white sand cement mortar. | Total porosity and water absorption values decreased with increasing irradiation dose, compressive strength values for polymer modified cement mortars increased with increasing irradiation dose while[2] The structure of quartz were not change when were irradiated by gamma-doses [3] Polymer-impregnated blended cement (OPC–RHA–UPE) paste irradiated at a dose of 30 kGy has a good resistance towards sulfate and seawater attack as compared to the neat blended cement (OPC–RHA) paste[4] |
| 2  | 50 – 300kGy | Quartz (SiO₂)                    | High gamma-irradiation doses on natural quartz crystals by ESR technique Ordinary Portland cement with 5% of active rice husk ash (RHA) are impregnated with unsaturated polyester resin (UPE) followed by gamma rays ranging from 10 to 50 kGy | The structure of quartz were not change when were irradiated by gamma-doses [3] Polymer-impregnated blended cement (OPC–RHA–UPE) paste irradiated at a dose of 30 kGy has a good resistance towards sulfate and seawater attack as compared to the neat blended cement (OPC–RHA) paste[4] |
| 3  | 10 to 50 kGy | Ordinary Portland cement with 5% of active rice husk ash (RHA) | | |
| 4  | 10^{22}n/m² or 12MGy | KU1 fused silica | Concentration of E'-type defects and oxygen-related defects produced in KU1 samples irradiated with high neutron fluences | highest fluence generate a much higher concentration of defect than gamma irradiations at highest dose [5] |
| 5  | 12MGy       | Fused Silica                    | Relevence of the manufacturing process (defects and impurities) present in the material before irradiation. Neutron Irradiation introduces highest clustered regions compared to all other performed irradiation experiments with reduced generation of point defects[6] | Impurities and defects produced during the manufacturing process of the silica are defect at least up to 12MGy doses[6] |
| 6  | Neutron 10^{14} cm⁻², gamma & proton | Epitaxial silicon material | Radiation induced defects and their differences observed in various kinds of epitaxial silicon material Defect parameters on high resistivity silicon with different concentrations of the impurities oxygen and carbon irradiated with neutrons and charged particles. | Irradiation with neutrons mainly create clusters single isolated displacements is enhanced due to Coulomb scattering.[8] |
| 7  | 10 – 50kGy  | Polymethyl methacrylate alite composite | Effect of gamma exposure dose on the physico-chemical and mechanical properties of polymer-alite composit. | Polymer loading, compressive strength and bulk density increase with increasing absorbed dose. The formation of new products in the pores appeared after impregnation.[9] |
| 8  | 1.332 -1.173 MeV | Basaltic Rock fragment | Gamma-ray irradiation on water-rock reactions are investigated by comparing leaching experiments with and without irradiation Water-rock interaction is promoted by gamma-ray irradiation in most cases of major basalt constituents, the absorbed dose are contained more in the feldspars[10] Fast-neutron irradiation induces substantially higher optical losses in the pure-silica core of the CeramOptec fiber than in the F-doped silica cladding[11] | |
| 9  | Silica      | High-energy radiation towards silica-core optical fiber | | |
| 10 | Synthetic silica glasses | Defect of E’ centers by irradiation of gamma. | | |
| 11 | Paper       | Filtration properties of four different filter papers on basis of the results of fibers swelling determination | | |
| 12 | 50-300kGy   | | | |
3.1. Effect of radiation on polymer
Based on table 1 above, row number 1, 3 and 8, the gamma radiation causes both cross-linking and degradation during treatment. Cross-linking is the most important effect of polymer irradiation because it is usually accompanied with an increase of the number of the polymeric chains under the effect of irradiation dose, leading to the formation of a network structure. Several studies indicated that, during irradiation polymerization an interaction between calcium silicate hydrate formed during the hydration reaction of the blended cement and the polymer presents in the pores takes place.4

3.2. Effect of radiation on paper
Gamma irradiation of the filter paper as in row number 12 in table 1, induces the swelling restrictions of cellulose fibers. The effects of paper simultaneously and progressively with prolongation of gamma-irradiation.

3.3. Effect of radiation on silica
Based on table 1, row number 2, 4, 5, 6, 7, 10 and 11 shows the effect of irradiating various types of radiation on silicon especially used for fusion and fission reactor environment. Overall, it shows that a higher gamma dose causes higher changes in microstructure such as pairs defects on E‘ center and an oxygen hole center. But for pure SiO₂ or quarts, radiation does not induce any changes on the microstructure. Meanwhile, irradiation with neutrons mainly causes clusters are create while using charged particles the generation of single isolated displacements is enhanced due to Coulomb scattering.

4. Conclusion
The defects of materials especially silica and paper depended on neutron and gamma energies. For the filtration system to be studied we propose to use 12MGy gamma doses and 1022n/m² neutron fluence on the silica and paper in the system. The results from previous experiment can be a benchmark for the further study on comparing the quality index of filtrated water using gamma and neutron irradiated basic filter element.

5. References
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