Analysis of radioactivity concentration in natural rubber latex and radiation prevulcanized natural rubber latex (RVNRL)

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Abstract. Radiation vulcanization of natural rubber latex (RVNRL) is an alternative technology to conventional sulphur vulcanization. To eliminate some public members sceptical view toward the radioactivity of the prevulcanized latex produced using gamma radiation, RVNRL was prepared at several radiation doses and then their radioactivity concentration were measured using gamma counting technique. The activity concentration level of Ra-226, Th-232, and K-40 in RVNRL found to be not significantly different from non-vulcanized natural rubber latex (NRL). The reported radioactivity proved that using gamma radiation in the RVNRL preparation could not ionized and produce radioactive materials from NRL minerals. Hence, it is concluded that RVNRL is safe to be used as the main raw material in latex dipped products industry.

1. Introduction
Natural rubber latex (NRL) is a non-elastic sticky milky fluid that was harvested from Hevea brasiliensis. It has a spherical shape with a diameter between 0.02 - 3 µm, and protected by a layer of the complex film consisting of proteins and lipids as shown in Figure 1. The rubber particles contain almost 99 % of the rubber hydrocarbon chain with the Cis-1,4-Polyisoprene isomer [1].

To improve its elasticity and thermal stability, the NRL will undergo the vulcanization process. At present, three popular vulcanization processes are being used in NRL industries, namely sulphur, radiation and peroxide vulcanizations.
The production of prevulcanized natural rubber latex by radiation technology is not new in Malaysia. It was first introduced in the mid-1990s by the Malaysian Nuclear Agency. Radiation vulcanization is an alternative technology to the conventional crosslinking process by using sulphur and its other chemicals ingredient. The use of radiation do not only produced radiation prevulcanized natural rubber latex (RVNRL) that can be used for the production of nitrosamines free products, it also able to excludes type I and IV allergies that caused by chemicals and high protein content in the products i.e. glove, finger coat, balloon, condom etc. [1].

When it comes to the use of nuclear technology in the industries, some public members are very sceptical about the products produced. Some of them though the products will become radioactive and emit radiation that might give health risk. The though is certainly not true because the products exposed to radiation for sterilization, decontaminations and crosslinking purpose, will not turn into radioactive material. In addition, the public are unaware that natural radiation is also present around them at background level i.e. soil and food (Table 1 and Table 2). Study on the acceptance of irradiated products like food has been studied by [4]. Most of the respondent has a neophobia and negative though on the irradiated food and had low intent to purchase irradiated food. In the field of medical, the used of neutron by the source of boron, $^{10}$B $(n,a) ~ ^7$Li to treat cancer has showed that the patients became radioactive and their $^{24}$Na in blood can be detected via a Na-I scintillation counter [5]. Society’s perception should not be underestimated, and therefore, the radioactivity level and concentrations for Radium-226 (Ra-226), Thorium-232 (Th-232) and Potassium-40 (K-40) will be investigated and measured to fend off such misconceptions.

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**Figure 1.** Structure of natural rubber latex [2].
Table 1: Comparison of radioactivity concentration for Ra-226, Th-232, and K-40 in soil

| Location | Level    | Activity concentration (Bq/kg) | References |
|----------|----------|--------------------------------|------------|
|          |          | Ra-226 | Th-232 | 40K     |            |
| Malaysia | Minimum  | 38     | 63     | 170     | UNSCEAR 2000 |
|          | Maximum  | 94     | 110    | 430     |            |
|          | Average  | 67     | 82     | 310     |            |
| Thailand | Minimum  | 11     | 7      | 7       | UNSCEAR 2000 |
|          | Maximum  | 78     | 120    | 712     |            |
|          | Average  | 48     | 51     | 230     |            |
| China    | Minimum  | 2      | 1      | 9       | UNSCEAR 2000 |
|          | Maximum  | 440    | 360    | 1800    |            |
|          | Average  | 32     | 41     | 440     |            |
| Japan    | Minimum  | 6      | 2      | 15      | UNSCEAR 2000 |
|          | Maximum  | 98     | 88     | 990     |            |
|          | Average  | 33     | 28     | 310     |            |
| India    | Minimum  | 7      | 14     | 38      | UNSCEAR 2000 |
|          | Maximum  | 81     | 160    | 760     |            |
|          | Average  | 29     | 64     | 400     |            |
| Worldwide| Average  | 35     | 30     | 400     | UNSCEAR 2000 |

Recently, Toyen et al. [1] from Thailand reported that the radioactivity concentrations for Ra-226, Th-232 and K-40 in the Thailand’s NRL were 29.9 ± 1.1, 95.2 ± 1.2 and 96.2 ± 1.0 Bacquerel/kilogram (Bq/kg) respectively (Table 2). The reported value proved that natural radionuclide present in NRL, even in small concentration. As for Malaysia, based on the UNSCEAR report (2000), the average of natural radioactivity concentrations for Ra-226, Th-232 and K-40 in soil were 67, 82 and 310 Bq / kg respectively as showed in Table 1. We are confident that the rubber trees and NRL produced in Malaysia also consist of radioisotopes with specific radioactivity concentrations. Hence, for this study, radioactivity level in raw NRL produced in Malaysia (Jelebu, Negeri Sembilan) were measured and RVNRL prepared at various radiation doses will be analyzed using the gamma counting technique.
Table 2. Radioactivity concentration of Ra-226, Th-232, and K-40 in agriculture/crops/commercial products.

| Type of agriculture/crops/commercial products | Level | Activity concentration (Bq/kg) | Location | References |
|-----------------------------------------------|-------|-------------------------------|----------|------------|
| Rice (originated from cultivated fields tilled with phosphogypsum) | Minimum | 0.36 | Thessaloniki, Northern Greece | (Papastefanou et al., 2006) |
|                                                | Maximum | 1.98 |          |            |
|                                                | Average | 1.53 |          |            |
| Pasta                                          | Average | 0.068 | 0.078 | 0.049 | (Pearson et al., 2016) |
| Vegetables                                     | Minimum | 46.05 | 9.29  | 325.89 | Turkey | (Bolca et al., 2007) |
|                                                | Maximum | 68.83 | 50.57 | 530.52 |        |            |
|                                                | Average | 34.8  | 210.5 |       |        |            |
| Cosmetic products (natural clay based)         | Minimum | 57.8  | 34.8  | 996.3  | Greek | (Papadopoulos et al., 2014) |
|                                                | Maximum | 168.0 | 75.5  | 210.5  |        |            |
|                                                | Average | 115.6 | 49.7  | 658.4  |        |            |
| Tobacco                                        | Average | 4.56  | 3.94  | 1289.53| Egypt | (Shyti et al., 2019) |
| Natural rubber latex                           | Average | 29.9  | 95.2  | 96.2   | Thailand | Toyen & Saenboonruang (2020) |
| RVNRL (prepared at 12 kGy)                     | Average | 30.8  | 89.1  | 95.4   | Thailand | Toyen & Saenboonruang (2020) |
| RVNRL (prepared at 24 kGy)                     | Average | 31.2  | 89.7  | 93.2   | Thailand | Toyen & Saenboonruang (2020) |

2. Materials and methods

2.1. Materials
The latex utilized in this work is a high ammonia type of latex (HA latex) supplied by Titi Latex Sdn Bhd, Malaysia. The sensitizer used were hexanediol diacrylate (HDDA) supplied by Allnex, China. The stabilizer used was potassium laurate supplied by Tiarco Chemical (M) Pt. Ltd., Malaysia and the antioxidant used was Aquanox Lp supplied by Aquaspersion (M) Pt. Ltd., Malaysia. These materials were used as received.
2.2. Preparation of RVNRL compounding formulations
A typical latex compounding formulation for RVNRL preparation is given in Table 3. The sensitizer, stabilizer, antioxidant, and water homogenized were used to form an emulsion before it was added into the latex and was stirred gently. Once the addition of the emulsified materials completed, the latex mixture was stirred for three hours \[7\]. It was then transferred into a one-liter screw-capped plastic container and irradiated with gamma rays produced by Cobalt-60 source at a dose of 10, 20, and 30 kGy. After 6 hours of irradiation, the RVNRL was formed into a film by the coagulant dipping method.

| Materials | Part per hundred (phr) |
|-----------|------------------------|
| NR Latex (62% Total Solid Content) | 100 |
| Stabilizer | 0.06 |
| HDDA | 2.50 |
| Antioxidant | 2.50 |
| Water | Add to 52% Total Solid Content |

2.3. Measurement of radioactivities
The radioactivities measurement for Non-vulcanized natural rubber latex (control) and RVNRL were measured by using gamma counting technique. The rubber films stacks in 350ml screw-cap geometry container were sealed, and incubated for 21 days. This is to allow Ra-226 decay to Rn-222 and achieve secular equilibrium. The entire sample spectrum individually measured with the well-calibrated gamma ray spectrometry consisting of a high-purity germanium (HPGe) setup and multichannel analyzer of 16,384 channels. The detector used is a coaxial 3 inches diameter closed end, closed facing window geometry with vertical dipstick (500 – 800 um) operated at 3,500 HV bias supply \[8\].

The activities of Ra-226 were calculated through its progeny energy peaks i.e. Pb-214 and Bi-214, for Th-232 (Ra-228) were calculated through Ac-228 peak energy, while K-40 was calculated via directly its energy peak \[9\]. All radioactivity calculations applied for density corrections \[10\].

3. Results and discussion
The radioactivities for Ra-226, Th-232, and K-40 in both non-vulcanized NRL and RVNRL were presented in Table 4. The activity concentration of Ra-226, Th-232 and K-40 from NRL produced at Jelebu, Negeri Sembilan found to be far lower compared to NRL planted in Thailand (Table 2) \[6\]. This varies happened due to geographical differences (minerals in soil) and tree clones. Aside from that, it is noticeable the presence of relatively high K-40 in NRL and RVNRL. As expected, potassium is the essential element and the most abundant inorganic mineral nutrient in plant cells due to its functions as a stabilizer in metabolism and an osmoticum contributing to cellular hydrostatic pressure and growth \[11\].

According to Makuuci 2003, the radiation energy more than 10 Mega electron volt (MeV) are needed to activate materials to become radioactive, while in industrial applications typically used energies from 100 Kilo electron volt (KeV) up to 1 MeV. In the case of
gamma energy used to vulcanized NRL, 1.17 MeV are used [12]. Data obtained in Table 4 showed the radioactivity concentration in all samples relatively unchanged, proved that radiation vulcanization technique does not increase the radioactive nuclide of NRL minerals. This finding has proven that in terms of radiological safety and radioactivities concentration, RVNRL is safe to be use as main raw material in latex dipped products industry.

| Sample          | Radioactivity level (Bq/kg) | Ra-226 | Th-232 | K-40 |
|-----------------|----------------------------|--------|--------|------|
| NRL (control)   | < 0.50                     | 1.10±0.08 | 34±11  |
| RVNRL 10 kGy    | < 0.50                     | 1.34±0.10 | 36±12  |
| RVNRL 20 kGy    | < 0.50                     | 2.98±0.22 | 29±9.8 |
| RVNRL 30 kGy    | < 0.50                     | 1.03±0.08 | 33±11  |

4. Conclusion
The radioactivity concentration level of Ra-226, Th-232, and K-40 in RVNRL prepared at a radiation dose of 10, 20 and 30 kGy is not significantly different from non-vulcanized NRL. This finding proved that using gamma radiation to prepare RVNRL will not ionize and produce radioactive materials from NRL minerals. Hence, we conclude that RVNRL is safe for the user as the main raw material in latex dipped products industry.

5. References
[1] Ma’zam M S 2005 Prevulcanized latices: course on latex concentrate production, prevulcanized and other modified latices (Malaysia: Lembaga Getah Malaysia).
[2] Sabharwal S, Das T N, Chaudhary Y K, Bhardwaj Y K and Majali A B 1998 Mechanism of n-butyl acrylate sensitization action in radiation vulcanization of natural rubber latex. Radiat. Phys. and Chem. 51(3) 309-315.
[3] Akademi Hevea Malaysia 2012 Kursus ujian latex Lecture note of Short Course on Latex Testing 25-28 Jun 2012 (Lembaga Getah Malaysia).
[4] Filho L, Lucia T Della, Lima R M 2017 Thoughts, attitudes and profile of Brazilian consumers regarding food irradiation Int. J. of Consumer Studies 41(5) 518–525.
[5] Fujiwara K, ;Kinas Y; Takahashi T; Yashima H; Kurihara K; Sakurai Y; Tanaka H, Takahashi S 2013 Induced radioactivity in the blood of cancer patients following boron neutron capture therapy J. of Radiat. Res. 54(4) 769–774.
[6] Toyen D and Saenboonruang K 2020 Determination of radioactivities in gamma vulcanized natural rubber latex (GVNRL) for the assessment of radiological safety. IOP Con f. Series: Materials Science and Engineering 773 012011.
[7] Sofian I, Khairiah B, Chantara T R and Ali N H M 2018 Enhancing mechanical properties of prevulcanized natural rubber latex via hybrid radiation and peroxidation vulcanizations at various irradiation. Radiat. Effects and Defects in Solids 174 223-233.
[8] Yii M W; Assyikeen M. J N, Zaharudin A 2011 Radiation hazard from natural radioactivity in the sediment of the east coast peninsular Malaysia exclusive economic zone (EEZ). The Malaysian J. of Analyt. Sci. 15(2) 202-212.
[9] Yang Y X ; Wu X M; Jiang Z Y; Wang W X; Lu J G; Lin J; Wang L.M. and Hsia Y F 2005 Radioactivity concentrations in soils of the Xiazhuang granite area, China Appl. Radiat. Isot. 63 255-259.
Yii M W and U’yun W M Z 2016 Ambient radioactivity and radiological studies in the vicinity of Lynas Rare-Earth Processing Plant, Gebeng Industrial Estate, Kuantan, Pahang Technical Report ScienceFund Project Nuclearmalaysia/L/2016/96.

Dreyer I, Uozumi N 2011 Potassium channels in plant cells FEBS J. 278 4293-4303.

IAEA 2005 <http://www-naweb.iaea.org/nafc/iachem/Brochgammairrad.pdf>. [16 July 2020].

Bolca M; Saç M M; Çokuysal B; Karali T; Ekdal E 2007 Radioactivity in soils and various foodstuffs from the Gediz River Basin of Turkey Radiat. Measur. 42(2) 263–270.

El-Reefy HI, Sharshar T, Zaghluor R and Badran H M 2006 Distribution of gamma-ray emitting radionuclides in the environment of Burullus Lake: I. Soils and vegetation, J. Environ. Radioact. 87 148-169.

Makuuci K 2003 An Introduction to Radiation Vulcanization of Natural Rubber Latex (Bangkok: T RI Global Co. Ltd.).

Pairu I; Manshol W Z W; Chai C K, Sofian I, Saadiah S, Sharifah I 2017 Safety evaluation test on human for radiation prevulcanised natural rubber latex (RVNRL). Sains Nuklear Malaysia. 29(1) 28-36.

Papadopoulos A; Giouri K; Tzamos E; Filippidis A, Stoulos S 2014 Natural radioactivity and trace element composition of natural clays used as cosmetic products in the Greek market Clay Minerals 49(1) 53–62.

Papastefanou C; Stoulos S; Ioannidou A, Manolopoulou M 2006 The application of phosphogypsum in agriculture and the radiological impact J. of Environ. Radioact. 89 (2) 188–198.

Pearson A J; Gaw S; Hermanspaeh N; Glover C N 2016 Natural and anthropogenic radionuclide activity concentrations in the New Zealand diet J. of Environ. Radioact. 151 601–608.

Shyti M; Cfarku F; Bërdufi I; Bylykyu E, Hoxha R 2019 Natural radioactivity in cigarette tobacco and radiation dose induced from smoking. AIP Conf. Proc. 2075(1) 91–95.

United Nations Scientific Committee on the Effects of Atomic Radiation Report 2000 <https://www.unscear.org/docs/publications/2000/UNSCEAR_2000_Report_Vol.I.pdf> [1 July 2020].

Yii M W, Lorensu H J K and Asri R Mohd 2019 Radionuclide concentration in surface soil of Nuclear Malaysia’s Bangi complex and its potential radiation risk Nuclear Technical Convention 2019 (Bangi, Selangor, Malaysia: Agensi Nuklear Malaysia).

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