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Design and Creating a Specific Neutron Irradiation Instrument to Decrease the User's Radiation Exposure Time

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Abstract:

A specialized irradiation instrument "created instrument" was designed and created from various kinds and sizes of available plastic household-waste materials. In addition, a neutron beam collimator with a lid was designed and implemented. The collimator is with dimensions of 25 cm in height and 10 cm in inner diameter, while the lid dimensions are 11.5 cm height and outer diameter of 9.9 cm to perfectly match the inner diameter of the collimator with the possibility of movement (opening and closing), and also the shielding of the radioactive ^{241}Am/Be neutron source with a recent activity of 37.5 mCi.

To investigate the efficiency of the "created instrument", ten hydrogenous material samples (ordinary paraffin of chemical structure C_nH_{2n+2}) with the same cylindrical dimensions (Ø = 8.5 cm, 0.5 cm thickness) and with the same weight of 20 g ± 0.005 for each, were used with and without the "created instrument". The neutron measurements were slowed (4.7 – 1.58 n/s) when the paraffin sample thickness was progressively increased (0 – 5 cm). Most importantly, the "created instrument" was effectively contributed to reducing the user's radiation exposure time from approximately 90 seconds to a few seconds no longer than 30 seconds for each measurement with considerable reduction ratio of 66.67% by making the samples of thicknesses ranging from 0.5 cm to 5 cm easier to position on the neutron beam collimator compared without using the "created instrument". It may also be utilized to evaluate the moderation on-site for different materials in neutron source shielding thickness based on the measuring procedures and data gathered. It is predicted that this study will help future improvements to use additional techniques to satisfy more protection related to the radiation field.

Keywords: Recycling available plastic household-waste materials, Created instrument, Irradiation instrument, Neutron beam collimator and cover, Paraffin, Exposure time, ^{241}Am/Be neutron source.

تصميم وإنشاء أداة خاصة للتشعيع النيوتروني لتقليل وقت تعرض المُستخدم للإشعاع

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الخلاصة:

تم تصميم وإنشاء أداة تشعيع متخصصة (الأداة المُنشأة) حيث صُنعت بجهود فردية من أنواع وأحجام مختلفة من النفايات المنزلية البلاستيكية المُتاحة بأبعاد نهائية بإرتفاع 35 سم. إضافة إلى تصميم وتنفيذ مُوجّه (مُحدّد/ ميزاء) الحزمة النيوترونية بإرتفاع 25 سم وقطر داخلي 10 سم، بالإضافة إلى غطاء مُوجّه الحزمة النيوترونية بإرتفاع 11,5 سم وقطر خارجي 9,9 سم ليتناسب تماماً مع القطر الداخلي لمُوجّه الحزمة النيوترونية مع إمكانية الحركة (الفتح والإغلاق)، وكذلك تدريع المصدر النيوتروني المُشع نوع أمريشيوم−241/ بريليوم ذو النشاط الإشعاعي الحالي مقداره 37,5 مللي كيوري.

للتحقق من كفاءة "الأداة المنشأة"، إستُخدمت عشرة عينات من المواد الهيدروجينية (البارافين العادي ذو الصيغة الكيميائية C_nH_{2n+2}) بنفس الأبعاد الإسطوانية (قطر 8,5 سم وسمك 0,5 سم) وبنفس الوزن (20 غم ± 0,005) لكل عينة، إستخُدمت هذه العينات مع وبدون "الأداة المنشأة". الأهم من ذلك، إن "الأداة المنشأة" قد ساهمت بشكل فعّال في تقليل وقت تعرض المُستخدم للإشعاع من 90 ثانية تقريباً لكل قياس إلى بضع ثوانٍ لا تزيد عن 30 ثانية لكل قياس بنسبة تخفيض معتبرة 66,67% بسبب سهولة وضع العينات ذات السمك من 0,5 سم إلى 5 سم في مُوجه الحزمة الإشعاعية النيوترونية مقارنة مع إجراء القياسات بدون إستخدام "الأداة المنشأة". كما يمكن إستخدامها أيضاً لتقييم إمكانية التباطؤ النيوتروني موقعياً للمواد المختلفة المستخدمة في تدريع المصدر النيوتروني بناءً على إجراءات القياس المُتبعة والنتائج المستحصلة. من المتوقع أن تساعد هذه الدراسة في التحسينات المستقبلية لإستخدام تقنيات (طرائق) أخرى لتحقيق المزيد من الوقاية المتعلقة بمجال الإشعاع.

1. Introduction:

Municipal and industrial polymer waste (plastic and rubber) is usually disposed of in landfill sites with no recycling management. As a result of on-going economic expansion and development, it is deteriorating by growing global pollution [1, 2]. The tough challenge is developing solutions for decreasing polymeric waste that is environmentally acceptable, cost-effective, and reusable [1, 3]. This study presents a method of making use of these wastes as a way of recycling them. On the other aspect, neutron shielding is complicated due to the fact that neutrons are not easily attenuated by matter since they interact with atoms of matter solely through their nuclei [3, 4]. one of the most notable materials employed in nuclear facilities dating back to the famous experiment of James Chadwick that resulted in the discovery of neutrons in 1932, is paraffin (C_nH_{2n+2}) [5]. The high hydrogen content of paraffin, its cheap cost, moldability, and superior electrical insulation make it suitable for use as a neutron moderator and shield [6, 7]. Fast neutrons are more difficult to protect against since their absorption cross sections are significantly smaller at higher energy. As a result, high-speed neutrons must first be moderated by elastic or inelastic scattering interactions [8]. The mechanism of paraffin for use in thermal neutron shields is based mostly on elastic scattering between neutrons and paraffin hydrogen nuclei in order to significantly reduce neutron energy [9]. However, the total thermal neutron cross-section of hydrogen nuclei is quite low, 0.33 barns for neutron absorption cross-section and 82.02 barns for total neutron scattering cross-section, resulting in low interaction probabilities and the need for significantly thick paraffin sheets to effectively shield thermal neutrons [9, 10]. In radiation protection, the exposure dose in the vicinity of an external radiation source can be reduced by increasing the distance from the source, by minimizing the time of exposure, and by shielding suitable to the type of radiation. These are denoted as the three golden rules; distance, time, and shielding [11, 12]. Another guiding principle for radiological protection management is commonly known as "ALARA" principle (as low as reasonably achievable). Thus, this principle means that even if it is a small dose, if receiving that dose has no direct benefit, you should try to avoid it [11-13].

The aim of this paper is to build a special irradiation instrument, named “created instrument” from the available plastic and aluminium household-waste materials. This “created instrument” can easily be moved, when exposing paraffin samples to the radioactive ^{241}Am/Be neutron source, in such a way so as to reduce the radiation exposure time for the user. In addition, a neutron beam collimator with a lid was designed and implemented and the shielding for the recent neutron source.

2. Experimental Work:

In the present work, several kinds of available plastic and aluminium household-waste materials with different dimensions (height H, inner diameter $Ø_I$, and outer diameter $Ø_O$), as illustrated in Table 1 and shown in Figure 1, were used. These pieces were collected to create a special irradiation instrument (created instrument) which was surrounded by paraffin from the middle between its inner and outer sides except the central hole, with final dimensions of 35 cm H, 8.5 cm in bottom $Ø_I$ till 5 cm in height, 10 cm $Ø_O$, 13 cm $Ø_O$, and 7 cm in top $Ø_I$ till 30 cm in height along the central hole, as shown in Figure 2 and sketched in Figure 3 and easy manually movable to expose samples to the neutron source. In addition, a neutron beam collimator with a lid was designed and implemented. The collimator is with dimensions of 25 cm height and 10 cm inner diameter; the dimensions of the lid are 11.5 cm in height and an outer diameter of 9 cm, to perfectly match the inner diameter of the collimator and to allow for opening and closing of the lid.and also the shielding of the radioactive ^{241}Am/Be neutron source with a recent activity of 37.5 mCi by using personal efforts and available radiation protection means, as shown in Figures 4 and 5.

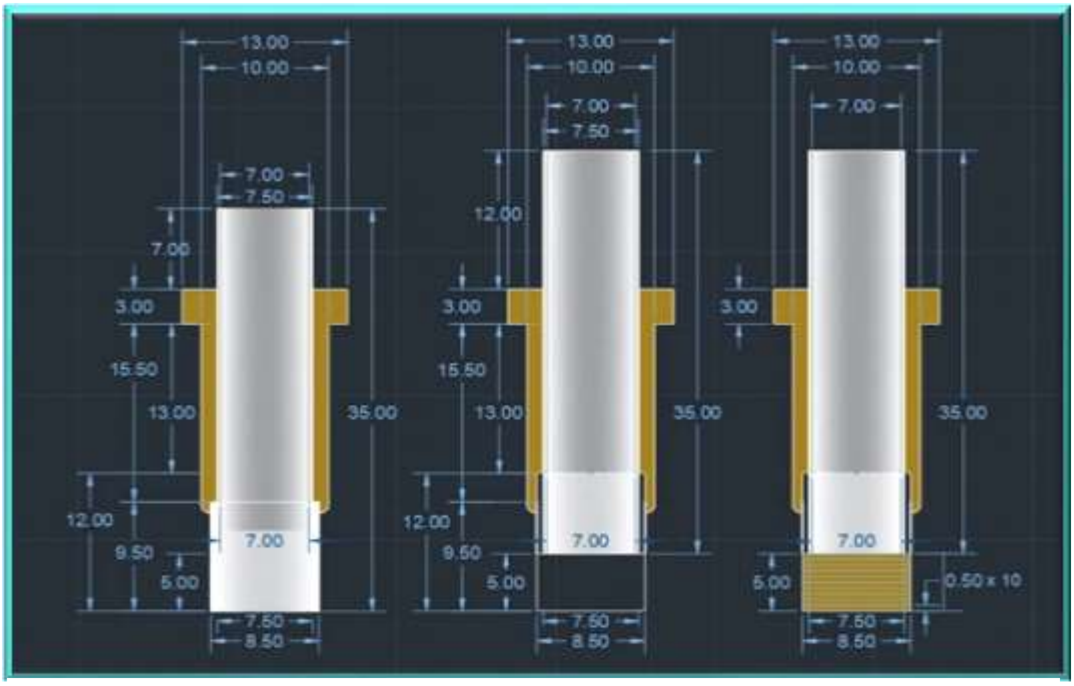
Portable detection device, “identiFINDER NGH ultra”, with three internal detectors: NaI(Tl) scintillation of cylindrical shape (1.4" X 2"), GM tube for gamma radiation detection and moderated ^{3}He tube for neutron detection was used [14]. The identiFINDER NGH ultra device was calibrated at the Iraqi Radioactive Sources Regulatory Authority, IRSRA, using standard calibration method with ^{137}Cs radioisotope. Ten ordinary paraffin samples with identical cylindrical dimensions (Ø = 8.5 cm and 0.5 cm thickness) each of 20 g ± 0.005 weight were used and placed gradually to increase thickness, These samples were successively gradually placed in the bottom side of the "created instrument" in a safe place away from the neutron source, and then all were positioned vertically in the neutron source's beam collimator. An efficient portable detection device with high response detectors, "identiFINDER NGH ultra", was used to measure the neutron count rate for each of the ten samples. The measurements were recorded at the top side of the "created instrument" (35 cm from the backside of the first sample of 0.5 cm in thickness) for a period of time not exceed ten seconds for each time, and also the procedures were repeated for the cumulative thickness of the samples up to 5 cm. Then investigated via exposing them to ^{241}Am/Be neutron source with average energy 4.5 MeV [8, 15], as shown in Figures (6) and (7). The neutron count rate beyond each paraffin sample was measured after samples exposing.

Table 1: Dimensions for several kinds of available plastic and Aluminium household-waste materials.

Waste materials	Height cm	Inner diameters (ØI) cm		Outer diameters (ØO) Cm	
Plastic (PVC)	25	10		10.5	
Plastic	17.5	8.5 Bottom	10 Top	8.55	10.05
Plastic	17	7.5	8.5	7.55	8.55
Plastic (PVC)	25.5	7		7.5	
Plastic (PVC)	9.5	7.5		8	
Plastic	3	7.5		13	
Plastic (PVC)	2	7.5		8	
Plastic (PVC)	1	10		10.5	
Aluminium	11.5	9.8		9.9	

Figure 1: Several kinds of available plastic household-waste materials with different sizes.

Figure 2: Design and create the irradiation instrument (created instrument) which surrounded by paraffin from the middle between its inner and outer sides except the central hole.



(A) (B) (C)

Figure 3:- Sketch in centimetre unit for the created instrument; A closed case, B opened case, and C opened case with loaded paraffin samples.

Figure 4: Design and create the neutron beam collimator.

Figure 5: Design and create the cover for neutron beam collimator.

Figure 6: Samples preparation and loaded in the created instrument.

Figure 7: Shielding design, identiFINDER NGH ultra device, and measurements.

3. Results and Discussion:

The neutron measurements were slowed (4.7 – 1.58 n/s) when the paraffin thickness was progressively increased (0 – 5 cm) as shown in Table 2 and Figure 8. Most importantly, the "created instrument" was effectively contributing to reduce the user's radiation exposure time from approximately 90 seconds to a few seconds no longer than 30 seconds for each measurement by making the samples of thicknesses ranging from 0.5 cm to 5 cm easier to position on the neutron beam collimator compared without using the "created instrument". There is no similar data in the literature because this newly designed instrument (created instrument) is unique.

Table 2: Neutron count rate measurement in paraffin material

Thickness cm	Neutron count rate n/ s	Thickness cm	Neutron count rate n/ s
0	4.7	3	2.11
0.5	3.9	3.5	1.89
1	3.4	4	1.73
1.5	3.25	4.5	1.65
2	2.85	5	1.58
2.5	2.38	---	---

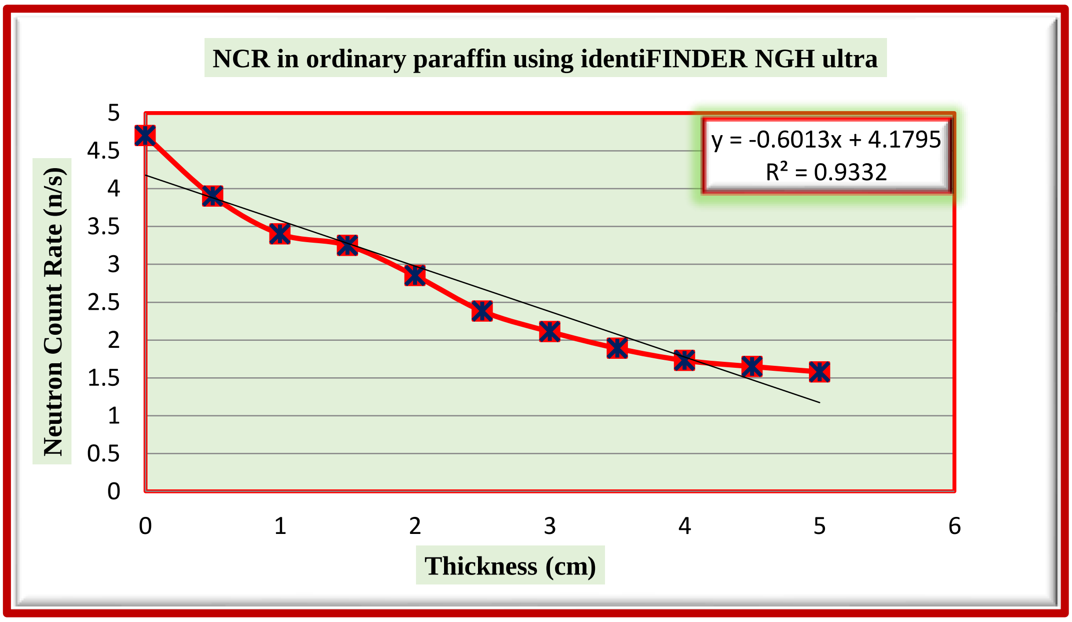


Figure 8: Neutron count rate for paraffin material using portable device identiFINDER NGH ultra.

The findings displayed in Figure 8 demonstrated a definite drop in the neutron count rate as sample thickness increased up to 5 cm; moreover, the fitting equation derived from the plotted data demonstrated a continuing decrease in the neutron count rate for higher thickness than utilized. The results of neutron count rate (n/s) in ten paraffin samples obtained with "identiFINDER NGH ultra" revealed a significant decrease in percentage ratio by 66.4%. Most importantly, radiation exposure time was lowered by a considerable ratio of 66.67% when the "created instrument" was used.

4. Conclusions:

The newly "created instrument" was effectively contributing into reducing the user's radiation exposure time from approximately 90 seconds to a few seconds no longer than 30 seconds for each measurement, with a significant reduction ratio of 66.67 percent by making samples with thicknesses ranging from 0.5 cm to 5 cm easier to place on the neutron beam collimator when compared to not using the "created instrument", as well as protecting the user from radiation exposure for a distance of no less than 35 cm, and also the shielding concept was satisfied. Based on the measurement procedures and data acquired, it may also be used to evaluate the moderation on-site for different materials in neutron shielding thickness. It is predicted that this study will help future improvements to use additional techniques to satisfy more protection related to the radiation field.

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