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Irradiation Experiment for Living Insect-Based Radiological Dispersal Device

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Abstract

People generally associate fear with “nuclear”, “radioactive” and “insects”. It is speculated that a release of radioactive living insects would instill more fear into the general public than a “traditional” style radiological dispersion device (RDD). This paper evaluates the potential threat of an insect-based RDD using experimental data. The results of this project found that insect-based RDDs are an insignificant threat due to the challenges in making insects radioactive enough to pose any danger to humans without killing the insects.

I. Introduction

On September 11, 2001, terrorists hijacked four planes and attacked predetermined targets in the United States. Since then, there has been a considerable amount of discussion in both the media and scientific community regarding radiological dispersal devices (RDDs), or so-called dirty bombs. An RDD combines a conventional explosive device—such as a bomb—with radioactive material. It is designed to scatter dangerous and sublethal amounts of radioactive material over a general area [1]. Discussions about RDDs have been focused on the types that could conceivably be used, their physical and psychological impacts on society, and how an adversary could acquire the radioactive materials needed for such a bomb’s construction.

One potential production pathway would be to irradiate insects with neutrons. This method’s principle challenge is to expose the insects to optimal levels of neutron radiation—i.e., to yield enough radioactivity for each insect to be viable as an RDD without killing the insects by exposing them to too much radiation. Many studies have investigated the effects of radiation on insects; those most relevant to this paper are summarized below. D. Wharton and M. Wharton at the Quartermaster Research and Engineering Command irradiated various groups of American cockroaches with a 2-MeV electron accelerator. Their results showed that the radiosensitivity of the roaches was influenced by both the age and gender of the specimens, with older and male cockroaches being more radiosensitive. For radiation doses of 10 krad, 50% of the cockroaches died within seven days. The survival decreased to three days at 40 krad, while at doses of 250 krad no cockroaches remained alive beginning at 1.25 hours after irradiation [2]. Morris Rockstein also reported that insects’ radiosensitivity is determined by many factors, including the age of the insect, with older insects being more radiosensitive. However, at doses of 500 kR from a 662 keV ^{137}Cs gamma rays source, all insects will die within 24 hours. For doses in the 100 to 300 kR range, there will be clustering of deaths within a one-week period [3].

In the 1950s, J. M. Cork, a researcher in the Department of Physics at the University of Michigan, irradiated flour beetles using a ^{137}Cs source to determine the rate at which the insects died after irradiation. His results showed that for doses of 11, 15, and 20 kR, the fractions of flour beetles still alive at thirty days after irradiation were approximately 57%, 27%, and 4%, respectively [4]. S. El-Naggar and A. Mikhael of the Egyptian Atomic Energy Authority irradiated flour beetles, cigarette beetles, rice moths, and lesser grain borers, using a ^{60}Co source. Results from their irradiations, at 50, 100, 200, and 400 krad showed that the various insects had considerably different radiosensitivity, but more than 50% of all insects died within one day at a dose of 400 krad [5]. These studies demonstrate that both age and species of the insect play significant roles in determining how much radiation insects can tolerate. It appears that the lethal dose for 50% of cockroaches within one day is between 40 and 100 krad. We suspect that insects have much lower radiosensitivity than mammals because insects' cells divide only when they are molting [6].

A living insect-based RDD would likely be less radioactive than what many consider a traditional RDD because of radiation limitations during neutron activation. However, reduced radioactivity may not detract from the effectiveness of such a device because many experts feel the primary threat of an RDD is the ensuing public panic rather than the effects of radiation exposure [1]. Additionally, the fact that insects are mobile and found nearly everywhere combined with the fact that some people fear non-radioactive insects [7] could make a living insect RDD a more effective weapon for terrorists intending to effect mass disruption more than injury and death. It is also noted that this kind of RDD's contamination area could be larger due to the mobility of insects and the fact that whenever they defecate, molt, or die, those locations become contaminated. This paper evaluates the potential threats from a new type of RDD involving radioactive living insects. Experiments were conducted using different types of living insects in two separate neutron facilities. The experiments showed that living insects were unlikely to become a significant threat because of the short lifetime or the low activity of the insects after irradiation. Given the random motion of the insects after release, they can, however, be a major source of mass disruption to the general public.

II. Experimental Setup

This research project was accomplished through two separate experimental campaigns. These experiments focused on proof of principle that insects could be activated to a level that poses a health threat to humans and that this level of radioactivity could last for at least several days. The first was conducted in spring 2006 using the 1-MW Teaching Research Isotopes General Atomics (TRIGA) reactor at Texas A&M University [8]. This experiment involved qualitative neutron activation analysis on dead German cockroaches. The second measurement campaign occurred in spring 2016 using the deuterium-deuterium (D-D) neutron generator at the University of Sharjah in the United Arab Emirates. The generator setup includes three neutron ports, which are capable of providing fast (2.45 MeV) and thermal neutrons [9]. These latter experiments focused on quantitative neutron activation analysis on living crickets.

A. Texas A&M University

Twenty-two living German cockroaches—male and female, and at different lifecycle stages—were obtained from the Texas A&M Department of Entomology. Due to administrative requirements, the cockroaches were killed using liquid nitrogen before conducting the irradiation experiment. All nitrogen was allowed to evaporate and dissipate before irradiating the cockroaches. Six dead cockroaches were placed in two plastic vials (three per vial) that were then placed in an aluminum can and inserted into the TRIGA reactor pool which had a Maxwellian neutron flux distribution [10] at the lower flux (LF) position. The sample was irradiated for eight hours at a total flux level of 2.45×10^{12} n/(cm²-s). After irradiation, the on-contact dose rate was measured at 80 mR/hr, which dropped to 5 mR/hr ninety minutes later. While at this reduced dose rate, each vial was measured for ten minutes live time using a High Purity Germanium (HPGe) detector.

A follow-up activation experiment was conducted with sixteen dead cockroaches placed in two plastic vials (eight per vial) and then placed in an aluminum can. The can was placed in a higher flux (HF) position, 6.58×10^{12} n/(cm²-s). The irradiation time was eight hours, with the sample reaching an on-contact dose rate of 310 mR/hr at nineteen hours after irradiation and 5 mR/hr at 112 hours after irradiation. While at this reduced dose rate, each vial was measured for sixty minutes live time using an HPGe detector.

B. University of Sharjah

Twenty-seven living crickets were obtained from a pet shop in Abu Dhabi and sorted into three groups; a “fast” group (eight crickets) to be irradiated with a ~65% fast neutron flux, a “thermal” group (ten crickets) to be irradiated with a ~50% thermal neutron flux, and a control group (nine crickets) which was not irradiated. Each group of crickets was placed in an airtight plastic bag with the fast and thermal groups being placed in their respective beam ports in the neutron generator. The crickets were irradiated for one hour at a total neutron flux level of 2.2×10^6 n/(cm²-s) for the thermal port and 5.4×10^6 n/(cm²-s) for the fast port. At six minutes and fifteen seconds after irradiation, the crickets from the thermal group were measured using an HPGe detector for five minutes live time. Eight minutes after irradiation, the crickets from the fast group were measured using a separate HPGe detector for five minutes live time. The thermal and fast groups were measured at different intervals after irradiation due to personnel limitation. After performing and evaluating these initial measurements, longer—twelve-hour—live time measurements were made. These measurements were made using the same HPGe detector at 3.5 hours after irradiation for the fast group and 16.5 hours after irradiation for the thermal group.

III. Results and Discussion

All the radioactive nuclides created in the insects had short (≤ 36 hours) half-lives, with the exception being ⁶⁵Zn ($t_{1/2} = 244$ days). It should be noted that the results include possible activation of the plastic vial/bag that contained the samples. The activity of all measured radionuclides was decay-corrected to the end of activation using Eq. 1 [11].

$$A_o = \frac{C \cdot \lambda}{\gamma \cdot \varepsilon_{geo} \cdot \varepsilon_{int} \cdot e^{-\lambda t_d} \cdot (1 - e^{-\lambda t_c})} \quad (1)$$

Where A_o is the radionuclides activity, C is the counts created from the gamma-ray of interest, λ is the decay constant, γ is the yield of the gamma ray per decay, ε_{geo} is the geometric efficiency of the detector system for the gamma ray, ε_{int} is the detector intrinsic efficiency for the gamma ray, t_d is the time between the end of the activation and the start of the gamma-spectroscopy measurement, and t_c is the duration of the spectroscopy measurement.

A. Texas A&M University

Spectroscopic analysis of the measurements taken at Texas A&M University found activation products induced in the cockroach samples: ²⁴Na, ⁴²K, ⁵⁶Mn, ⁶⁵Zn, and ⁸²Br. Of these radionuclides, only ⁶⁵Zn ($t_{1/2} = 244$ days) had a half-life longer than 36 hours. With sample activities above 10,000 MBq for the HF positions—and given that the majority of this activity comes from ²⁴Na, which emits two high-energy gamma rays (1,369 keV and 2,754 keV) per decay—an insect-based RDD could pose a radiation hazard for days after activation. The results of the spectroscopic analysis are provided in Table 1.

Table 1: Activity of the isotopes detected at Texas A&M University, decay-corrected to the end of activation.

Isotope	Half-life [hours]	Activity – vial 1-LF [MBq]	Activity – vial 2-LF [MBq]	Activity – vial 1-HF [MBq]	Activity – vial 2-HF [MBq]
²⁴ Na	14.95	236.8 ± 4.9	218.5 ± 4.5	9,357 ± 195	8,466 ± 176
⁴² K	12.36	51.7 ± 2.9	48.5 ± 2.7	4,514 ± 110	4,205 ± 101
⁵⁶ Mn	2.58	1.26 ± 0.13	1.25 ± 0.13	-	-

^{65}Zn	5,851.2	-	-	7.55 ± 0.56	8.21 ± 0.62
^{82}Br	35.30	-	-	2.17 ± 0.03	1.89 ± 0.03

B. University of Sharjah

Spectroscopic analysis of the measurements taken at the University of Sharjah found the presence of ^{24}Na and ^{56}Mn in some of the measurements, shown in Table 2. Figure 1 shows an example spectrum for the 12-hour duration fast group measurement.

Table 2: Activity of the isotopes detected at the University of Sharjah, decay-corrected to the end of activation.

Isotope	Half-life [hours]	Activity – 10 minute fast group [Bq]	Activity – 10 minute thermal group [Bq]	Activity – 12 hour fast group [Bq]	Activity – 12 hour thermal group [Bq]
^{24}Na	14.96	-	-	4.78 ± 0.33	2.47 ± 0.35
^{56}Mn	2.58	5.9 ± 2.6	-	12.8 ± 1.4	-

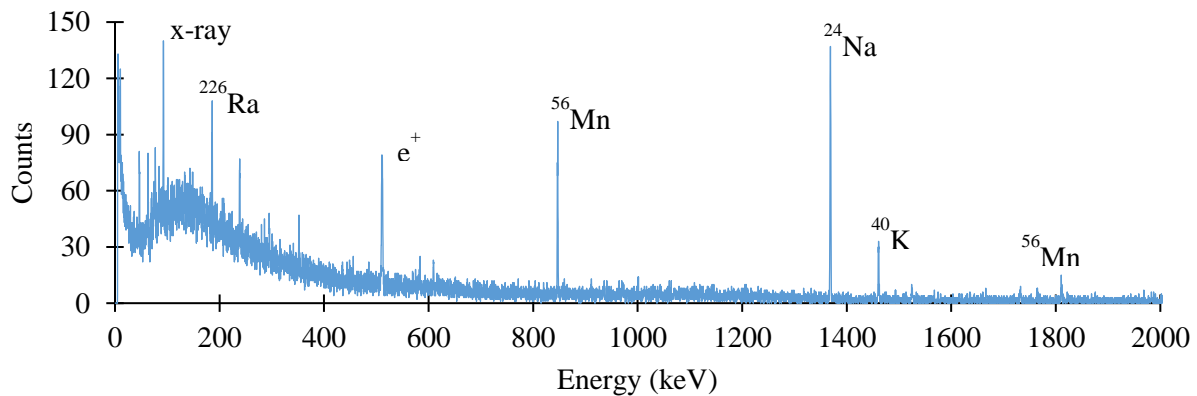


Figure 1: Example spectrum for the 12-hour duration fast group measurement showing the presence of ^{24}Na and ^{56}Mn along with background isotopes.

To estimate the maximum activation the crickets could endure before dying, the number of living crickets was counted at 18 hours and 42 hours after activation. See Table 3.

Table 3: Number of living crickets in each group before and after irradiation.

	Fast	Thermal	Control
Living insects, before irradiation	8	10	9
Living insects, 18 hours after irradiation	3	10	8
Living insects, 42 hours after irradiation	1	7	6

It is difficult to draw precise conclusions due to the poor health of all the crickets before irradiation. However, it is clear that there were fewer living crickets in the fast group than the control group. In addition, the thermal and control groups had approximately the same number of living crickets at both 18 and 42 hours after irradiation. Estimations of the total dose each group received were determined using International Commission on Radiological Protection (ICRP)-21 conversion factors and benchmarked Monte Carlo N-Particle (MCNP) simulations to be 480 rem (fast) and 110 rem (thermal) [12, 13]. Based on results from the open literature, described earlier, these levels of radiation doses should not have a noticeable effect on the immediate health of the crickets. As such, it is suspected that the fast group crickets died of non-radiation dose causes, possibly thermal exposure due to the 3-kW beam current [14, 15].

IV. Conclusions

Terrorist radiological weapons are a concern for both experts and the general public. One variant of such weapons that could potentially increase the psychological effect, and thus the overall effectiveness, of an RDD is radioactive living insects. This project sought to determine the threat of such a weapon—whether it is possible to make living insects radioactive enough to create panic without killing the insects with radiation exposure.

The experiments at Texas A&M University showed that it is possible to activate dead insects using a nuclear reactor so that they emit significant levels of radiation. Most of the radionuclides created in the insects were short-lived with half-lives less than 36 hours, with the exception being ^{65}Zn , which has a half-life of 244 days.

Experiments at the University of Sharjah using living insects found that neutron activation using a neutron generator is possible, but the radionuclides activated have short half-lives (≤ 15 hours) and low activities.

While this endeavor has shown that it is possible to activate living insects and detect their radiation in a laboratory setting, it is unlikely that an insect-based RDD would be an effective weapon in terms of posing a radiation hazard. The insects would probably quickly die from the radiation exposure or, if insufficiently irradiated, would have very low activities compared to natural background. Even if the insects survived the radiation exposure and created a radiation hazard, their radioactivity would rapidly decrease to background levels within a few days to a week due to the short half-lives of the activated radionuclides. In addition to the low radiation threat posed by an insect-based RDD, it might be difficult for terrorists to access neutron sources needed to activate the insects. An insect-based RDD would, however, still be an effective tool of fear and panic in civilian areas, even though (and indeed because) its path of flight would be largely unpredictable.

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