Radioactive decay model based on augmented reality

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Abstract. This article presents a simulation model of radioactive chain decay with augmented reality technology. Radioactive decay is classified as abstract material that is difficult to understand. This simulation will make abstract radioactive decay materials easily understood. In this article will explain the simulation changes to the $4n + 2$ radioactive model by utilizing augmented reality technology. This media development uses the black-box testing method to test the accuracy and validity of the software program. Interactive media using augmented reality on radioactive decay have been able to display the U-238 chain decay model (series $4n + 2$) by simulating the process of alpha and beta release in each series. This simulation successfully displayed a striking difference between alpha and beta release in the U-238 chain reaction cycle.

1. Introduction
Radioactive decay is classified as hazardous material in practicum. Using augmented reality (AR), simulations will help protect the effects of radiation in real practice, without reducing the fact of a radiation process. Radioactive accidents are cause for concern. To reduce these impacts, AR-based simulations can be a solution [1]. AR simulation is also able to support the process of drawing conclusions and optimizing procedures in the critical thinking aspects of a procedural [2].

The effectiveness of AR has been expanded in various fields. The use of augmented reality has been proven to be able to improve students' abilities and enhance the ability of science processes [3]. Much media development research is carried out to support students’ knowledge, especially in radioactivity material, such as the use of radioactive animation using AR [4], the application of AR to Geiger Muller counter [5], electronic books using 3D Pageflip [6], and virtual reality simulation on models water infiltration for radioactive waste in the environment [2].

This article will present a simulation of changes in the $4n + 2$ radioactive model by utilizing augmented reality technology. The simulation of the decay of the $4n + 2$ series begins with the decay of Uranium-238 to Thorium-234 during the half-life of 4.47 billion years [7]. The difference in alpha and beta decay at each stage of radioactive decay [7] is a concern of this simulation.

This research aims to visualize the chain reaction concept from that device using augmented reality technology. The results of this simulation will be used to regulate the parameters of radioactive simulation in other series of radioactive.

2. Methods
This simulation has the main objective to visualize the chain reaction of radioactive series $4n + 2$. The 3D animation of the radioactive nucleus is visualized in a granular mass which is a visualization of a collection of neutrons (Yellow) and protons (red) shown in Figure 1. Atomic nucleus, when in an
unstable state, will visualize vibration and will stop when it reaches stability. In each given period, the core will release alpha (Figure 2), which consists of double proton double neutron, or beta, consist of the electron (Figure 3).

![U-238](image)

**Figure 1.** Nuclei of Uranium-238.

![Alpha decay](image)

**Figure 2.** Alpha decay.

![Beta decay](image)

**Figure 3.** Beta decay.

This media development uses black-box testing to test the accuracy and accuracy of this simulation software program. Software testing is the most often applied technique for verifying and validating the quality of software [8]. Black box testing is commonly used to validate the right software [9].

![Research flow](image)

**Figure 4.** Research flow.

Research conducted using the Black-box Testing type Boundary Value Analysis (BPA). The stages of the study are shown in Figure 4. The input conditions in this study are limited by the values 0 (Failed) and 1 (Success). If the input conditions determine the range defined by values a and b, test cases must be designed with values a and b and just above and just below a and b [10].

3. Results and discussion

3.1. Development results

Simulation has been developed by visualizing it in animation. Interactive media using augmented reality on radioactive decay can display the concept of chain decay by simulating the process in each series of alpha and beta releases. The $4n + 2$ series decay simulation begins with the decay of Uranium-238 to Thorium-234 during the half-life $t_{1/2}$ of 4.47 billion years [7]. The half-time table is shown in Table 1 below.
Table 1. Half Time 4n + 2 Series [7,11,12].

| Parent Nuclide | Decay Mode | $t_{1/2}$ | Daughter Nuclide |
|----------------|------------|-----------|-----------------|
| $^{238}$U | Uranium-238 | $\alpha$ | $4.47 \, \text{Gigayear}$ | $^{234}$Th |
| $^{234}$Th | Thorium-234 | $\beta^-$ | $24.10 \, \text{day}$ | $^{234}$Pa |
| $^{234}$Pa | Protactinium-234 | $\beta^-$ | $6.69 \, \text{hour}$ | $^{234}$U |
| $^{234}$U | Uranium-234 | $\alpha$ | $2.45 \times 10^5 \, \text{year}$ | $^{230}$Th |
| $^{230}$Th | Thorium-230 | $\alpha$ | $7.6 \times 10^2 \, \text{year}$ | $^{226}$Rn |
| $^{226}$Ra | Radium-226 | $\alpha$ | $1.6 \, \text{kiloyear}$ | $^{222}$Rn |
| $^{222}$Rn | Radon-222 | $\alpha$ | $3.823 \, \text{day}$ | $^{218}$Po |
| $^{218}$Po | Polonium-218 | $\alpha$ | $3.04 \, \text{minute}$ | $^{214}$Bi |
| $^{214}$Bi | Bismuth-214 | $\beta^-$ | $26.9 \, \text{minute}$ | $^{214}$Po |
| $^{214}$Po | Polonium-214 | $\beta^-$ | $19.7 \, \text{minute}$ | $^{214}$Bi |
| $^{210}$Pb | Lead-210 | $\beta^-$ | $22.6 \, \text{year}$ | $^{210}$Bi |
| $^{210}$Bi | Bismuth-210 | $\beta^-$ | $5.01 \, \text{day}$ | $^{210}$Po |
| $^{210}$Po | Polonium-210 | $\alpha$ | $138.4 \, \text{day}$ | $^{206}$Tl |
| $^{206}$Pb | Lead-206 | stable | - | - |

The chain reaction of Uranium-238 to achieve stability in the element Lead-206 is shown in Figure 5. This process also releases alpha and beta at each time step.

Figure 5. Schematic decay chains for 238-U. The half-lives shown are those compiled in Copper AND Reid [12].

The simulation successfully displayed the difference between alpha and beta release in the chain reaction cycle. The process of using this simulation begins by scanning for markers that have been identified by Vuforia. The marker used is illustrated in Figure 6. The application can also be downloaded via QR Code (Figure 7). Users only need to scan and install the Uranium-238 simulation application.
The simulation results demonstrate a chain-reaction series of Uranium-series $4n + 2$. Starting from Uranium-238 and heading to the stability of the element Lead-206. Simulation results are shown in Figure 8 in beginning and Figure 9 in the result of reaction. Initially (Fig. 8), the unstable uranium had 146 neutrons and 92 electrons. This unstable atom has a half-life of 4.47 Giga years and emits alpha particles [7]. Within a specified period, stability will be achieved in the lead element, which has 124 neutrons and 82 protons (Fig. 9).

In each release of alpha and beta decay, the nucleus of the atom in the radioactive element, will periodically decrease and depend on what is emitted from the element. The stages of decay are shown in Table 2.

| Decay Type | $A$ | $Z$ | Emitted | Comment |
|------------|-----|-----|---------|---------|
| $\alpha$   | -4  | -2  | Alpha particle: 2 Neutrons + 2 Protons |
| $\beta^-$  | Stay the same | +1 | Electron | Neutron changes into a proton and Loses an electron |
| $\beta^+$  | Stay the same | -1 | Positron  | Proton changes into a neutron and Loses a positron |

Each alpha $\alpha$ decay, radioactive elements will release two neutrons and 2 protons from the nucleus, thereby affecting the Mass Number ($A$) to be reduced by four numbers and Atomic Number ($Z$) by two numbers. In contrast, Beta Minus $\beta^-$ releases one electron by converting neutrons into protons, also in Beta Plus $\beta^+$ released by Positrons by changing protons into neutrons. The difference between alpha (Figure 10) and beta release (Figure 11) in the Uranium-238 chain reaction is shown in this figure.
3.2. Test result
Testing is done on simulation software using BPA type black-box testing. Flowchart of the developed application is shown in Figure 12.

Tests carried out in the augmented reality application response process are shown in Table 3. Testing is done using an android smartphone with an android system 8.1.0 (Android Oreo). The test results show that of several test items. Obtained test results are displayed in the following table.

Table 3. Black box testing results.

| No | Field                                      | Success rate | Interpretation |
|----|--------------------------------------------|--------------|----------------|
| 1  | Installation                               | 100 %        | Valid          |
| 2  | Starting                                   | 100 %        | Valid          |
| 3  | Initiating Marker                          | 100 %        | Valid          |
| 4  | Displaying Nucleus (E₁ - Eₙ)               | 100 %        | Valid          |
| 5  | Emitting Alpha and Beta (E₁ - Eₙ)          | 100 %        | Valid          |
| 6  | Animating the explosion of nuclei          | 100 %        | Valid          |
|    | Average of all Field                       | 100 %        | Valid          |
From the test results, the percentage of the function success in the application system is 100% valid. The progress of the system was reviewed from 42 items from 6 aspects that successfully passed the test. Testing the augmented reality device in Table 3 results in the conclusion that the application can run properly on an android smartphone 8.1.0 (Android Oreo System). The display generated from this application is made interactive so that users can play it. Augmented reality with interactive systems has been developed in developing instructional media, such as developing Lorentz simulations that students can play [13], organize the student hand-on activity in laboratory [14,15], and developing interactive electromotive force simulations [16]. The development of interactive AR needs to be developed to improve the quality of simulations in the world of education.

4. Conclusion
In conclusion, we succeeded in simulating a chain reaction system that works through the concept of decay of the series \(4n + 2\). Augmented reality applications in this study were made using an interactive interface and using programming to be interactive. This system can be used to analyze differences in the visualization of alpha and beta decay solutions in radioactive decay. This simulation has implications for the perception of chain reactions in physics learning media to get a better understanding. After testing with the black-box testing method, the test results are obtained that this application is valid and functioning properly.

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