The property of some materials to spontaneously emit radiation is called radioactivity. These materials are called radioactive; some are found naturally (e.g., Radium, Thorium, Uranium) and some have been produced by man (e.g., Neptunium, Fermium, Plutonium).

It has been determined that the emitted radiation comes from the nucleus of the radioactive atom as either Beta rays (which are electrons) and/or Alpha rays (helium nuclei), usually together with Gamma rays (photons with energies of X-rays or higher).

The original, or parent atom, disintegrates into another, different atom which is called the decay product, or daughter atom. When the decay product is not radioactive, the action will continue until all the parent atoms have become daughter atoms; at any time the total number of atoms is the same.

Figure (1) is a graph of the parent-daughter (stable) relationship with time, in this case starting with $N_0$ (a large number) parent atoms and zero daughter atoms.

Quite often the daughter atom is itself radioactive; its decay product can also be radioactive and so on until finally a stable, non-radioactive atom is produced. Such a situation is called a radioactive series, see Figure (2). Again, the total number of atoms at any time remains constant.

Analysis of experimentally obtained data about radioactivity, such as illustrated, has led to the following principles about radioactive atoms:

The probability for the disintegration of the radioactive atoms, in a given period of time is the same numerical value for each atom of the same kind.

This probability is independent of the past history or age of the atom.

The number of disintegrations per unit time, $\frac{dN}{dt}$, is proportional to the number of atoms present when this "activity" is measured. In graphs such as Figures (1) and (2) usually, instead of the actual numbers of the atoms, the activities are plotted versus time.

A very interesting derivation of the mathematical law of radioactive disintegration based only on the laws of chance can be found in "Physics of the Atom", Wehr and Richards, Addison Wesley, 2nd edition, 1967.

This statistical, or "chance", nature of radioactive disintegration, i.e., the unpredictability of an individual disintegration, was really the first experimental indication that the 19th century, causal, mechanistic treatment of physics could not be applied to all of physics.
The throwing of dice provides an opportunity to utilize the probability of a particular face turning up after the throw to create games of "chance."

Since the rate of radioactive decay depends on the "chance" of the disintegration of each single atom, an analog of radioactivity can be developed by substituting dice for the atoms and the probability of a marked face turning up after a die is thrown for the probability of an atom disintegrating.

Dice of various shapes and colors can be used to represent different atoms in a radioactive series and the ratio of marked faces to total faces can be varied to provide different probabilities for a marked face to turn up. Of course all the identical dice representing the same atom must have the same number of marked faces to insure the same probability of "disintegration" for each of the dice. It is convenient to use spheres to represent the final, stable, end products for there are no faces that can be marked, and turn up, to indicate a disintegration.

The dice need not have numbered faces. If one face of each die is "tagged" with a red dot, then after a throw any die found with a "tagged" face up is considered to have disintegrated.

Experimental data which yields graphs such as Figures 1 and 2, may be obtained with a very small sample of radioactive material. However even a one-tenth milligram sample would contain about a billion billion (1,000,000,000,000,000,000) atoms.

Such large numbers of dice can not be provided in a radioactivity analog. Therefore, due to the randomness of chance, it can not be expected that the Dice-Atom analog, with a small number of dice, will give very smooth disintegration curves. In this apparatus 160 dice are provided for the parent set. By combining the results of several trials, results are obtained equivalent to many more dice. The randomness of chance remains but its overall effect is reduced.

It is interesting to consider combining 100 trials yearly in each of the 30,000 U.S. High Schools and to keep records until the number of atoms in the 1/10th milligram sample are equaled. To do this would take 300 billion years.

Inherent in the mathematical model of radioactive decay, which is used to represent the reality of the experimental results, is the need for a low probability for any single disintegration. Regular, or semi-regular, polyhedrons with low values of probability for a face turning up are therefore selected. It is also necessary to provide the means to tumble these polyhedrons very well in order to achieve the expected probabilities.

It has been possible to construct a dice-analog (Cat No A-200) which simulates very closely the last part of the Actinium Radioactive Series. This series starts with Actinium; the analog starts with Actinium B as the parent, the first daughter is Actinium C, the second daughter is Actinium C", and the stable end product is Actinium D, an isotope of Lead. See "Computations and Experiments in Physics", Cappelletto and Mainardi-Exp30-Analog of Radioactive Decay, Edwards Brothers, Pub., Ann Arbor, Mich., 1963.

The Analog apparatus consists of a storage tray with numbered nests for the dice, a throwing tray, a clear cover, the dice, spheres, and a red marker.

These fit together for convenient storage and the clear cover makes it possible to check that all the parts have been returned. 20-faced colored dice (160) make up the parent set, 8-faced dice (80) of a different color make up the daughter set, and 160 spheres make up the stable end product.

The dice are originally unmarked and the marker is used to mark the faces with red dots. Allow an overnight drying period for the red dots to avoid dissolving them with hand perspiration. To keep the probabilities low, the 20-faced dice can each have 1, or 2, or 3 faces marked with red dots; all must have the same number of dots. Also, the 8-faced dice can each have 1 or 2 faces marked; again all must have the same number of dots.

Note the red dots can be removed with cleansing powder and water.

On page 4 are graphs (for very large numbers of atoms) of the smooth curves given by the mathematical model for all six possible combinations of the above mentioned parent and daughter markings.

The graphs resulting from performing the analog can be compared to these.

Two basic experiments can be performed with the Dice-Atom Analog.

I. Radioactive atoms disintegrating directly to a stable end product.

II. Radioactive parent atoms disintegrating through one radioactive daughter to a stable and product.
Whenever removing dice or spheres from the storage tray always take them from the lowest numbered nests first. Whenever returning dice to the storage tray always put them into the highest numbered nests. The highest uncovered number will always be the number of these particular dice or spheres in the throwing tray. The total for dice and spheres in the throwing tray must always be 160. Always start with all the 20-faced dice (previously marked in the throwing tray and the storage tray nearby.

Exp. I - Parent - Daughter (Stable)

Remove all the 8-faced dice from the storage tray and store these away in some convenient container. All the spheres remain in their nests.

Prepare a sheet of graph paper so that a plot similar to Figure (1) can be made for the Number of Atoms versus the number of Throws.

Plot 150 parent atoms and zero end product atoms for the "0th" throw.

Cover the throwing tray and tumble very well. Then pick out all the 20-faced dice which have come to rest with a marked face up, return these to the storage tray, and replace them in the throwing tray with an identical number of spheres.

Plot the number of 20-faced dice and the number of spheres now in the throwing tray versus the "1st throw".

Repeat the tumbling and replacement of "disintegrated" 20-faced dice for about 20 or 30 throws. Plot the number of 20-faced dice and spheres in the throwing tray after each throw.

Then for the parent and end product data connect the respective sequences of plotted points by a sequence of short straight lines. Short straight lines are used between the successive plotted points to convey the fact that no additional data could have been obtained for the intervals between the integral number of throws. Smooth curves can be fitted to the plotted points for the parent (and for the daughter) as can be considered extrapolations to the result that would be obtained using many more than 160 parent atoms at the "0th throw".

Plotted data equivalent to more than 160 parent atoms at the start can be obtained by combining the data obtained by several groups of students. Then it will be easier to fit smooth curves to the plotted points for a better extrapolations.

Exp. II - Parent - Daughter - End Product

Start with all the 8-faced dice and all the spheres in their storage tray nests.

Prepare a sheet of graph paper so that (depending on faces marked on the dice) a plot similar to the corresponding graph on page 4 can be made for the Number of Atoms versus the Number of Throws.

Plot 150 parent atoms, zero daughter atoms, and zero end product atoms for the "0th throw".

Cover and tumble very well. Pick out all the 20-faced dice which have come to rest with a marked face up, return these to the storage tray, and replace them in the throwing tray with an identical number of 8-faced dice.

Plot the number of 20-faced dice and the number of 8-faced dice in the throwing tray and zero spheres versus the "1st throw".

Cover and tumble. Pick out all the 8-faced dice and 20-faced dice which have come to rest with a marked face up. Return the 8-faced dice to the storage tray and replace in the throwing tray with an identical number of spheres. Then return the 20-faced dice to the storage tray and replace in the throwing tray with an identical number of 8-faced dice.

Plot number of 20-faced dice, 8-faced dice, and spheres in the throwing tray versus "2nd throw".

Repeat for about 20 to 30 throws.

Plot the number of 20-faced dice, 8-faced dice, and spheres in the throwing tray after each throw.

Then for the parent, daughter, and end product data connect the respective sequences of plotted points by short straight lines. Now see the last two paragraphs of the instructions for Exp. I.

The graph for either Exp. I or Exp. II can be compared qualitatively to its corresponding graph on page 4.

The Half-Life (in throws) of the parent atom can be determined from its decay curve. Its Disintegration Constant and Life Expectancy (average life) can also be determined; see reference to "Computations and Experiments in Physics" on page 2. This reference also explains how to analyze the growth and decay curve for the daughter atom. Note that, although fractional throws cannot actually be made it is convenient to measure to fractional values of throws when treating throws as analogous to time.