# Critical Mass

With the Critical Mass Demonstration, students gain a better understanding of critical mass and how a chain reaction can become uncontrolled. Students are able to visualize what is meant by subcritical, critical, and supercritical mass. By extension, this experiment is a useful analogy to nuclear fission. This experiment is best used by students working in groups.

### Grade Level

5-12

### Disciplinary Core Ideas (DCI)

5-ESS3-1, 3-5 ETS1-1, 3-5ETS1-2, MS-PS1-4, MS-PS3-4, MS-ESS3-1, MS-ESS3-3, MS-ESS3-4, MS-ESS3-5, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4, HS-PS1-1, HS-PS1-8, HS-PS3-3, HS-PS3-4, HS-ESS2-4, HS-ESS2-6, HS-ESS3-2, HS-ESS3-3, HS-ESS3-4, HS-ESS3-6

### Time for Teacher Preparation

**30-60 minutes** – To gather materials and set-up

### Activity Time:

**30-60 minutes** (1 Class Period)

### Materials

- Pen, Marker, or Pencil
- Student Data Collection Sheets
- 1 Stopwatch per group of students
- Balloons, light weight balls, ping pong balls, marshmallows, etc. (# of students * 2)
    - Alternatively, the activity can be demonstrated with mousetraps

### Safety

- It is important that students throw their balls straight up into the air and not aim directly for their fellow students.

### Science and Engineering Practices

- Ask questions and define problems
- Use models
- Plan and carry out investigation
- Analyze and interpret data
- Construct explanations
- Argue from Evidence
- Obtain, evaluate and communicate information

### Cross Cutting Concepts

- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter: Flows, Cycles, and Conservation
- Stability and Change of Systems

### Objectives

- Learn the concept of critical mass and how a chain reaction can become uncontrolled
- Define Critical Mass

### Background

The splitting of a massive nucleus into two fragments, each with a smaller mass than the original, is known as nuclear fission. A typical example of nuclear fission is the splitting of a uranium-235 nucleus. This is a reaction that is used in nuclear reactors to generate heat by which steam is produced and used to turn turbines that generate electricity. The fission of uranium-235 begins when the uranium-235 nucleus captures a slow moving neutron and forms an unstable "compound nucleus". The compound nucleus quickly disintegrates into two smaller nuclei, such as barium-141 and krypton-92, two or three neutrons (2.5 average), and a tremendous amount of energy (~200MeV per fission).

Because the uranium-235 fission reaction produces 2 or 3 neutrons, it is possible for those neutrons to initiate a series of subsequent fission reactions. Each neutron released can initiate another fission event, resulting in the emission of more neutrons, followed by more fission events, and so on. This is a chain reaction - one event triggers several others, which in turn trigger more events, and so on. In a nuclear power plant the chain reaction is controlled by restricting the number of neutrons available to collide with the uranium. This is accomplished by absorbing some of the released neutrons with various materials. In an uncontrolled chain reaction (such as an atom bomb explosion) there is nothing to control the number of neutrons being released, so the rate of the chain reaction increases dramatically.

There are two parameters needed to create a critical mass, the number of atoms and the spacing of the atoms. In this demonstration each student represents a uranium atom inside of a nuclear reactor. Each uranium atom releases two neutrons when it fissions. For this demonstration, the larger the number of student participants, the better the results.

# Energy Production

## Teacher Lesson Plan:

### Traditional

Arrange the students in a square array approximately 3 feet apart and give each student two balloons. Take a balloon for yourself and to begin the activity, throw your ball up into the air or at a student. Any student that is hit with this balloon throws their two balloons straight up into the air. Any student hit by these balloons then throws their balls into the air. The reaction continues until there are no more balloons in the air. The first time, the reaction will probably die out quickly, this is called **subcritical**.

Repeat the process, but place the students only 1 foot apart this time and carry out the activity. This time, the reaction should be self-sustaining. This is called **critical** and a critical reactor is running at a steady state.

Repeat the process a final time, but place the students in a tight array without any space between them. This time, there should be lots of balloons in the air at one time. This represents a **supercritical mass**, or when a reactor is increasing its power level.

### Variation

Replace the students with mousetraps and place them in an array. Set the traps and place a ping pong ball on each one. Be careful not to get your fingers caught in the traps, as sometimes they will go off when you set the ball on them. Then drop a ball on the array and watch the ball bounce around, setting off more traps. View demo at http://www.nuclearconnect.org/in-the-classroom/for-teachers/mouse-trap-reactor

### Optional Exercise

In a nuclear reactor, the reaction is controlled by control rods. These are special rods that go in between groups of fuel rods (which have fuel pellets stacked in them) inside the reactor. The control rods help to start (when they are removed), stop (when they are fully inserted), increase or decrease (when they are partially removed or inserted) the fission process.

Explain that students will now demonstrate a controlled reaction. Use the same students to be atoms or select a new group. Choose one (or more) additional student(s) to be a control rod. Their job is to stand inside the "atoms" group and try to grab or bat away the falling balloons before they hit a student. Since there are now control rods in your demonstration, the first balloon may have to be thrown several times before it hits a student. After all the balloons are thrown, discuss what happened. Fewer students should have been hit because the control rods intercepted some of the "neutrons." Students can see how the rods slow down and can even stop a chain reaction. When that happens, the fission process will stop very quickly.

### NGSS Guided Inquiry

Split students into small groups and give each student two balls. Have students design an experiment to model nuclear fission and critical mass with the balls acting as neutrons in a reactor.

### Student Procedure

1. Hold a ball in each hand.
2. If you are hit by a ball, throw your balls straight up into the air without aiming directly at your fellow students.
3. Time and record how long each reaction lasts which is when the last ball is thrown in the air.

### Data Collection

Attached Student Data Collection Sheets

### Post Discussion/Effective Teaching Strategies

Questions provided on the Student Data Collection Sheets

### Questions

1. What happened during each trial and why?

### Assessment Ideas

Have students discuss the differences between how subcritical, critical, and supercritical masses.

### Differentiated Learning/Enrichment

Have students discuss how the different arrangements of students affect the reactor reaching subcritical, critical, or supercritical masses.

### Enrichment Question

1. How do you think nuclear power plants use this concept to power up or power down?

### Further Resources

*For additional information:*

http://www.atomicarchive.com/Fission/Fission3.shtml

http://hyperphysics.phy-astr.gsu.edu/hbase/nucene/moder.html

*ANS Center for Nuclear Science and Technology Information*

http://www.nuclearconnect.org/in-the-classroom/for-teachers/classroom-activities

# Critical Mass

Student Data Collection ANSWER Sheet

## Objectives

- Investigate the concept of critical mass and how a chain reaction can become uncontrolled
- Define Critical Mass

Critical Mass is the point where the chain reaction can become self-sustaining.

## Procedure

Hold a ballooon in each hand.

If you are hit by a balloon, throw your balls straight up into the air without aiming directly at your fellow students.

Time and record how long each reaction lasts which is when the last ball is thrown in the air.

## Questions

1. What happened during each trial and why?

They should describe how one ball caused another to be thrown to demonstrate a simple chain reaction.

2. Be specific about the difference in the number of ‘reactions’ which occur during the trial.

The difference in the number of reactions should explain how about half the students were hit by balls each reaction.

## Enrichment Question

1. How do you think nuclear power plants use this concept to power up or power down?

Answers should include the concept of shielding yourself from the ball hitting you which slows down the reaction.

Answers could also talk of having the students have one ball or every other student having two balls. That way the students in-between can act as moderators.

## Energy Production

# Critical Mass

## Student Data Collection Sheet

Name: ______________________________

Date: ______________________________

### Objectives

- Investigate the concept of critical mass and how a chain reaction can become uncontrolled.
- Define Critical Mass

### Procedure

Hold a ball in each hand.

If you are hit by a ball, throw your balls straight up into the air without aiming directly at your fellow students.

Time and record how long each reaction lasts which is when the last ball is thrown in the air.

### Questions

1. What happened during each trial and why?

2. Be specific about the difference in the number of 'reactions' which occur during the trial.

### Enrichment Question

1. How do you think nuclear power plants use this concept to power up or power down?