Preliminary information on the consequences of the nuclear disaster at Fukushima

Gordon J. Aubrecht, II
Department of Physics, Ohio State University, Marion, Ohio 43302 and Columbus, Ohio 43210.

E-mail: aubrecht.1@osu.edu

(Received 29 July 2011; accepted 23 September 2011)

Abstract
On 11 March 2011, an earthquake off the coast of Japan disrupted electricity and caused a tsunami that crippled three boiling water reactors and caused problems with the spent fuel storage at four reactor sites at Fukushima Daiichi. The best understanding of the accident and its consequences will be discussed. How can physics teachers best respond to this opportunity to discuss nuclear energy?

Keywords: Nuclear accidents, Research in physics education, Philosophy of science.

Resumen
El 11 de marzo de 2011, un terremoto frente a las costas de Japón interrumpió la electricidad y provocó un tsunami que afectó tres reactores de agua hirviendo y causó problemas con el almacenamiento de combustible gastado situada en Fukushima Daiichi. La comprensión mayor del accidente y sus consecuencias serán discutidos. ¿Cómo pueden los profesores de física responden a esta oportunidad para discutir sobre la energía nuclear?

Palabras clave: Accidentes nucleares, La investigación en enseñanza de la física, Filosofía de la ciencia.

PACS: 28.41.Te; 01.40.Fk; 01.70.+w **ISSN 1870-9095**

I. INTRODUCTION

The disaster at Fukushima Daiichi Units 1 to 4 occurred following an undersea earthquake off the coast of Japan on 11 March 2011. While not as much radioactive material was emitted by the crippled nuclear facilities at Fukushima Daiichi as at Chernobyl, and notably less strontium, cesium, and iodine isotopes were released, the Tokyo Electric Power Company (Tepco) reports the primary releases at 130 to 150PBq of iodine-131, 6 to 12PBq of cesium-137, with a total release of 370 to 630PBq [1]. This compares to, respectively, 1.8EBq, 85PBq, and 5.2EBq for Chernobyl [1]. The Fukushima accident joins the Chernobyl accident at Level 7 on the International Nuclear and Radiological Event Scale, the most serious possible designation ("major accident"). There was evacuation of citizens within ~30km of the Fukushima plant (with some outlier lobes) [2], the same as for Chernobyl exclusion zone. Measuring stations at the plant report dose rates of between 5 and 115mSv/h [3], while the natural background dose rate in Japan is about 0.1mSv/h.

The accident released a great deal of activity into ocean waters [3, 4]. Concentration of activity in ocean water adjacent to the plant has fallen from around 100MBq/L in early April to 1-2MBq/L in late June. For comparison, naturally-occurring nuclides in the Pacific Ocean are estimated to have a net activity of ~ 8.5ZBq, or to average about 17Bq/L, mostly from potassium-40, carbon-14, rubidium-87, and tritium. Even now, therefore, the ocean water in the neighborhood of Fukushima Diichi is about 100,000 times as active than before the accident, notwithstanding that the average activity of the Pacific Ocean has been increased negligibly.

The accident has remained in the news and suggests that it could be used as a reason for physics teachers at all levels to discuss the issues of radioactivity, radiation, activity, and dose with students.

II. STUDENT AND CITIZEN IGNORANCE OF NUCLEAR CONCEPTS

There is abundant evidence in the literature that students and citizens are ignorant of the basic ideas of nuclear physics and of radiation and radioactivity. The two phenomena of radioactivity and radiation. For example, seem to be indistinguishable in people's minds [5, 6, 7, 8, 9, 10, 11, 12, 13].

School students have been shown by Millar and coworkers to believe that irradiated objects become active themselves [5, 6] (true only in very restricted circumstances, such as irradiation by neutrons). However, Prather has found that physics majors [9, 10, 11] and

Aubrecht found that graduate students in education [12] are also prone to the same sorts of misunderstandings. Australian high school students judged γ radiation as more dangerous than α or β [8]. College students generally considered all forms radiation more or less equally dangerous [13]. Among the public, average citizens were found to be less knowledgeable than engineers or peace and environmental activists about nuclear energy [14]. Citizens' "beliefs were also significantly less specific" than those expressed by members of the other two groups [14].

One might ask where these misdirected ideas come from. This is essentially a hopeless task, as in the most countries local and national media report both correctly and incorrectly and, globally, movies often elide important points of fact or even ignore fact to make the story more interesting. An interesting anecdote is that the author was told by one graduate student he was interviewing that she had learned the incorrect idea she was stating from a teacher when in grammar school! This may be a widespread phenomenon; we have heard also that the sun rises (exactly) in the east and sets (exactly) in the west and that the sun in Ohio is directly overhead at noon, also ascribed by our students to information from former teachers. It is important to turn to the evidence when possible, as we have shown can be done in the latter cases with middle school students [15]. This should also be true for issues raised in students' and citizens' minds by nuclear accidents such as the one at Fukushima.

A. Examples of incorrect student ideas about heat and radioactivity

Students may think they know what radioactivity is, until they are asked. Here is a segment of an interview with the interviewer (I) and the student (S) discussing this point.

I: What are you using as your definition of radioactivity right now? What are you thinking of with that?

S: I think of those guys out in the suits and where those little things that go click click click.

I: Okay, so what part of that is radioactivity?

S: I think it is a particle.

I: So it is a particle that …?

S: I don't know, I think it is a particle that is formed from natural substances, and it, um, I don't know, I think it is just a particle.

I: And it is definitely in the air, and is it in carbon-14, too, is it in pencil lead, or does it come off of the carbon-14 pencil lead? [this question refers to a picture the interviewer had presented to the student].

S: It's in it, but it can be released, it can be released with heat, I don't know. I am totally guessing, well you want to hear my train of thought. I think that there is probably in carbon-14 because I remember learning that it was carbon plus 2. And that made it radioactive or something. And I think it is present I don't know where it comes from. I think it comes from natural sources.

Other students mentioned heat as well. One student said "The microscopic particles that are in the air are a lot slower, and not harmful and, um, um, less intense I guess". The student added, "I also thought that they were hot". This particular student's idea may have originated in the popular use of "hot" to refer to radioactive materials (we did not ask her whence it came). Another student was asked about the role of temperature in radioactivity and had a different view—he said, "I am not sure what, whether or not if it is colder, then there is more radioactivity detected from it, or if it is hotter, then there is more".

B. Examples of incorrect student ideas about half-life

Prather had identified some issues of misunderstanding of half-life. In Ref. 10, Prather writes: "an equal percent of these [college] students believe that the mass and volume of a radioactive substance will decrease in the period of a half-life." We had known of Prather's thesis research on this topic [9], and, as a result, asked high school students taking a special summer program at Ohio State Marion a question similar to Prather's. Many of these students expressed the belief that half of the mass (16 out of 18) and half of the volume (13 out of 15) will remain after one half-life.

III. WHAT CAN PHYSICS TEACHERS DO?

Physics teachers teach physics, and we can, in particular, teach about nuclear physics topics. The Contemporary Physics Education Project (CPEP) has a chart on nuclear science and a supporting website that is available to help teachers do that responsibly [16]. As in the case of medical doctors, first do no harm. It is possible to find out some of the preliminary ideas students have. The appendix presents a questionnaire we developed to ascertain students' ideas on topics related to nuclear physics that can be connected to nuclear reactors—radiation, radioactivity, irradiation, and contamination.

Several groups have worked on materials to teach these topics. Early ideas are found in Ref. 5. More lately, CPEP [17], Prather [10], Prather and Harrington [11], Aubrecht [18], and Johnson [19] have developed ideas and materials teachers can use.

IV. CONCLUSIONS

The mistaken ideas we have documented form a starting point for teachers. The questionnaire (Appendix) can help teachers determine where to begin to teach some ideas about nuclear physics and nuclear reactors.

Many energy textbooks, as, for example, *Energy* [20], have lengthy sections on nuclear reactors and how they work. Ref. 20 is unique in that it discusses the accidents at Three Mile Island and Chernobyl in detail in a form easily accessible to physics teachers.

ACKNOWLEDGEMENTS

We appreciate the assistance of David Torick with the interviews cited. This work was supported in part by the National Science Foundation, under grant DUE-9950528. The ideas are those of the author and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

[1] Tepco, *The Great East Japan earthquake and current status of nuclear power stations*, slide presentation, 16 June 2011, slide 13.
[2] International Atomic Energy Agency (IAEA), http://www.slideshare.net/iaea/radiological-monitoring-and-consequences-of-fukushima-nuclear-accident-2-june-2011, slide 7, accessed 6 July 2011.
[3] Tepco, *Radiation dose measured in the Fukushima Daiichi Nuclear Power Station*, http://www.tepco.co.jp/en/nu/fukushima-np/f1/index-e.html, accessed 6 July 2011.
[4] Buesseler, K., *Japan's irradiated waters: How worried should we be?*, CNN.com, 26 April 2011.
[5] Millar, R., Klaassen, K. and Eijkelhof, H., *Teaching about radioactivity and ionising radiation: an alternative approach*, Phys. Educ. **25**, 338-342 (1990).
[6] Millar, R., *School students' understanding of key ideas about radioactivity and ionizing radiation*, Public Understand Sci. **3**, 53-70 (1994).
[7] Henriksen, E. K. and Jorde, D., *High school students' understanding of radiation and the environment: can museums play a role?*, Sci. Educ. **85**, 189-206 (2001).
[8] Cooper, S., Yeo1, S. and Zadnik M., *Australian students' views on nuclear issues: Does teaching alter prior beliefs?*, Phys. Educ. **38**, 123-129 (2003).
[9] Prather, E. E., *An investigation into what students think and how they learn about ionizing radiation and radioactivity*, Ph.D. thesis, University of Maine, (2000).
[10] Prather, E. E., *Students' beliefs about the role of atoms in radioactive decay and half-life*, J. Geosci. Educ. **53**, 345-354 (2005).
[11] Prather, E. E. and Harrington, R. R., *Student understanding of ionizing radiation and radioactivity,* J. Coll. Sci. Teach. **31**, 89-93 (2001).
[12] Aubrecht, G., *Views of radiation and radioactivity found among preservice teachers*, AURCO J. **7**, 4-23 (2001).
[13] Aubrecht, G., *What physics students think about the hazards of microwave ovens*, in Physics Teacher Education Beyond (2000). Selected Contributions, edited by R. Pintó and S. Surinach, (Elsevier Editions, Paris, 2001), pp. 241-244.
[14] Maharik, M. and Fischhoff, B., *Contrasting perceptions of the risks of using nuclear energy sources in space*, J. Environ. Psych. **13**, 243-250 (1993).
[15] Aubrecht, G., Schmitt, B,, Crosley, A., Fogle, R., Miller, A. and Tanner, T., *Long-term observations of celestial objects in middle school astronomy*, AURCO J. **17**, 1-14 (2011).
[16] Contemporary Physics Education Project, Nuclear Science chart, see www.cpepweb.org/nuclear.html.
[17] Contemporary Physics Education Project, *The ABC's of Nuclear Science*, http://www.lbl.gov/abc/
[18] Aubrecht, G., *Radiation By Inquiry,* modules on detection, measurement, shielding, and decay available from the author.
[19] Johnson, A., *Radiation By Inquiry*, material available from the author.
[20] Aubrecht, G., *Energy*, 3rd Ed. (Pearson Prentice Hall, New Jersey, 2006).

APPENDIX

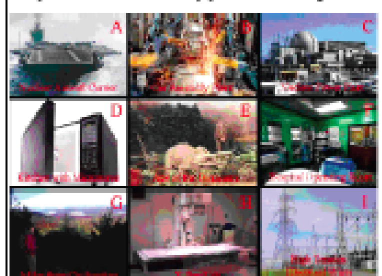
The appendix presents the questionnaire that can be used to determine student naïve ideas.

Nuclear Information Survey

1. Rank the situations displayed below from greatest to least, on the basis of the radioactivity that you would be exposed to if you were to be at that location.

Greatest 1 2 3 4 5 6 7 8 9 Least

If any amount of radioactivity you would be exposed to is the same, circle those cases together.



A. Nuclear aircraft carrier	B. Car assembly plant	C. Nuclear power plant
D. Kitchen with microwave	E. Age of the dinosaurs	F. Hospital operating room
G. Far away from civilization	H. X-ray lab	I. High tension Electrical wires

Please explain your reasoning carefully.

How sure were you of your ranking? (circle one)

Guessed Sure Very Sure
0 2 4 6 8 10

2. You cannot tell if a radioactive nucleus will decay in the next minute just by looking at the nucleus.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

Nuclear Information Survey

3. A radioactive substance is said to have a "half-life." What does the term "half-life" mean in this context? Please describe what happens to the mass and volume of the substance. What do individual atoms look like after they have decayed?

4. The number of decays in one minute is originally 2000 for a certain radioactive sample. Twenty days later, the number of decays in one minute from this same sample will be greater than 2000.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

Nuclear Information Survey

5. The lifetime of a large number of the same kind of radioactive nuclei can be accurately determined.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

6. As the temperature of a radioactive sample increases, so does its radioactivity.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

7. The atoms inside a cube of radioactive material are less likely to decay than atoms on the surface.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

Nuclear Information Survey

8. The ground around a nuclear power plant is contaminated by radioactive material.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

9. Particles in the environment coming from radioactive decay are going through my body all the time.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

Nuclear Information Survey

10. Consider a substance composed of radioactive atoms with a mass of 100 g and a volume of 150 cm^3. How would this substance change after one half-life? Explain your reasoning and draw a diagram to support your answer.

11. I know the difference between alpha, beta, and gamma radiation.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

Nuclear Information Survey

12. Viola is told she will be exposed to radioactivity. She wants a suit "like the Simpsons, they wear those suits to protect them from the radioactivity, it filters the air and keeps it away from your skin." If you were told you would ...

Disagree Tend to Disagree Be neutral Tend to agree Agree

Explanation:

13. A beta particle is more hazardous than an alpha particle.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

14. A beta particle is more hazardous than a gamma ray.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

Nuclear Information Survey

15. A gamma ray is more hazardous than an alpha particle.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

16. [a, b, or c] is an effective shield for [1, 2, 3] rays.
(Match the material with the respective ray in the brackets by drawing connecting lines below.)

a. Lead	1. alpha
b. Paperboard	2. beta
c. Aluminum plates	3. gamma

Explanation:

17. Being far away from a source of radioactivity makes a person safer.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

Nuclear Information Survey

18. Radioactivity of any sort is hazardous to health.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

19. Radiation does any damage it does because particles leaving the decay ionize the material they pass through.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

20. It is more dangerous to one's health to live at higher altitudes; so Denver (high in the Rockies) is more dangerous to live in than Seattle (at sea level).

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

Nuclear Information Survey

21. Radioactivity comes from [circle all that apply]:

outer space rocks garbage dumps x-ray machine in a hospital acid in rain

gas coming up from the ground factories a nuclear power station radios

22. People exposed to small doses of radiation are less likely to get cancer than those exposed to no radiation.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

23. A container of radioactive barium used in x-ray medical therapy is placed on a paper plate in a hospital room. The paper plate will become radioactive itself.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

24. There is a distinction between radioactivity and radiation.

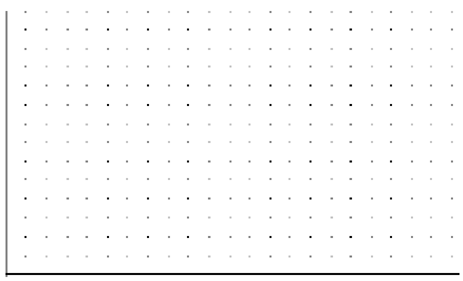
Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

25. Match the sources with the results. (multiple matches are possible.)

a. radioactive atom	1. radiation as waves
b. light bulb	2. radiation as particles
c. microwave oven	3. radio signals
d. x-ray machine	4. electricity
e. the Sun	5. heat

26. Graph the number of radioactive nuclei in a certain sample containing the same type of nuclei versus time below as well as you can. (x-axis: time; y-axis: number of radioactive nuclei)



Nuclear Information Survey

27. The count rate of 12 counts per minute is measured using a Geiger counter when nothing is nearby. A sample is brought near the counter and 15 counts per minute is measured. Therefore the sample is not radioactive.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

28. Since it is known that at least some forms of lead are radioactive, all lead must be radioactive.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

29. Radiation comes from [circle all that apply]:

outer space rocks garbage dumps x-ray machine in a hospital acid in rain

gas coming up from the ground factories a nuclear power station radios

30. Nucleus A decays into nucleus B and particle C. B and C are as radioactive as A.

Disagree Tend to Disagree Neutral Tend to agree Agree

Explanation:

Nuclear Information Survey

31. Consider a juicy strawberry, which is being exposed to radiation from a radioactive source (Case A). The source is then removed (Case B).

29A. Which, if any, of the three labeled items (1, 2, and 3) in Case A is radioactive? Explain your reasoning.

29B. Is the strawberry in Case B now a source of radiation? Explain your reasoning.

29C. Is the strawberry in Case B now radioactive? Explain your reasoning.