The Never-Ending Contamination:
Radioactivity and Half-Lives

by
Lior M. Burko
School of Science and Technology
Georgia Gwinnett College, Lawrenceville, GA

3:00 am. The bedroom phone was ringing. The ringing meshed together nicely with his dream, and he could see himself moving toward the phone in what seemed like an endless walk. He felt like Sisyphus; each time he reached the phone, he found himself back in bed getting up and starting to walk towards it again. Eventually the incessant ringing woke him, and he picked up the phone. The voice said, "Mr. President, we have a situation."

Within 15 minutes he was in a meeting with his chief of staff and the chairwoman of the USNRC, the United States Nuclear Regulatory Commission. The chairwoman cleared her throat and began. "The USNRC coordinates with the NNSA, the National Nuclear Security Administration. We have documented many incidents of lost radioactive materials amounting to about one incident per day. Usually it's just hospitals mislabeling or misplacing small amounts of weak radioactive sources used for radiotherapy or bone imaging purposes. But tonight we have a bigger problem. Much bigger. A large amount of iridium-192 was stolen from a metal plant where it is used for industrial gamma radiography to locate flaws in metal castings and welded joints."

That was enough to get the president's full attention. "Radioactive material theft? Are terrorists threating to explode a nuclear bomb in the U.S.? Where will it be detonated? How long do we have before the nuclear bomb explodes?"

The chief of staff, a former congressman from the president's home state, was quick to recover. "Mr. President, it's not a threat of a nuclear bomb. Iridium-192 is a dangerous radioactive material, and we've long suspected it could be used for a weapon. Tonight we've received intel that a sleeper cell with ties to an international terrorist organization is going to use this stolen iridium-192 for a dirty bomb."

The chairwoman further explained, "Mr. President, to make a nuclear bomb one would need both the release of high levels of energy from the nucleus, and the creation of a chain reaction. To create a chain reaction one needs fission, or breaking the nucleus into two roughly equal daughter nuclei, which is only rarely a naturally occurring phenomenon. It needs to be stimulated. In a naturally occurring radioactive decay the daughter nuclei are rather close in size to the mother nucleus, and the atomic number is different by no more than four. This is why iridium-192 can only be used as a dirty bomb."

"So it is a bomb?"

"Not a nuclear bomb per se, Mr. President," she answered. "A dirty bomb is sometimes called a radiological dispersion device, or RDD. The explosion is conventional. Maybe ten pounds of plastic explosives, or one stick of dynamite. That's the least of our problems. A dirty bomb combines radioactive material with conventional explosives so that the explosion is conventional rather than nuclear. But the explosion projects radioactive material outward and contaminates the area around the explosion. If a dirty bomb detonates in Manhattan, where our intel suggests it will, the immediate damage is expected to be between 10 and 100 people getting severely sick or killed from the initial explosion and the subsequent plume. A small number of people, closest to the explosion, are expected to suffer from acute radiation syndrome, or ARS."

The president sat for a moment, thinking of the press conference he would have to hold if such an event were ever to happen. "A single loss of life is one too many, but is this the only danger? If so, it's relatively minor and we can handle it."

"Well," the chairwoman continued, "the greater problem is going to be the ground contamination, which cannot be easily scrubbed away. We might need to tear down buildings from a number of city blocks that would become uninhabitable. The half-life of iridium-192 is 74 days, so complete city blocks might be uninhabitable for years. Iridium-192 decays to stable platinum-192 or osmium-192 by emitting a beta particle or by electron capture, respectively; most of these decays, 95%, are by beta emission and the remaining 5% by electron capture. They are accompanied by a complex gamma-radiation spectrum with energies between about 0.2 mega-electron-volts and 0.6 mega-electron-volts, peaking at 0.316 mega-electron-volts. These are the factors that make iridium-192 dangerous for causing radiation sickness."

The president didn't seem to be following. "Half-life? Remind me what that is."

"Half-life is the length of time it takes half of the unstable nuclear isotopes in any sample to decay. Each species of unstable isotope has a different half-life, and for iridium-192 the half-life is 74 days. Because of this value for its half-life, contamination would last years!"

The chief of staff intervened, "Well, if half of all the iridium decays after 74 days, then the second half will decay after another 74 days, totaling 148 days; that's less than six months, not years, and the problem is gone."

The chairwoman was quick to object. "No, sir, radioactive decay of one nucleus is independent of what other nuclei are doing. This means that after one half-life only half of the original radioactive nuclei are still there, and it will take another half-life for half of those to decay, leaving us with a quarter of the initial amount after two half-lives. After three half-lives there will be one-eighth left, and so on."

The president understood quickly and said, "But this means the radiation will never go down to zero!"

"That is almost correct, Mr. President," she replied. "The radiation will never go down to exactly zero if the initial sample is infinitely large. However, any real world sample is of a finite size, and for a finite size sample the radiation can go down to exactly zero. At any case, even for finite samples, after sufficiently many half-lives the number of decays per second will be low enough for the radiation level to be safe, and then it will go down below the background level. There is always some low-level radiation present, and we don't have to wait until all the radiation is gone, only until it drops back to safe levels. The background radiation comes mostly from naturally occurring radioactive elements from space, the sun, and the ground, and also from man-made sources such as medical devices in hospitals."

The president was considering this report carefully. "You said the half-life is 74 days. What are the implications of this to our immediate response and to long term habitability of this area?"

The chairwoman responded, "Some nuclear isotopes have very long half-lives. Some even have half-lives that are billions of years long. Those have important scientific applications, such as for determining the age of the solar system and even that of the Earth, but they would not be appropriate for a dirty bomb. The danger from a dirty bomb comes from isotopes with short half-lives, such as iridium-192."

The chief of staff added, "Our immediate response is to evacuate at least several city blocks around the explosion, and instruct citizens to stay inside. This will reduce exposure to any radioactive airborne dust. We will start emergency broadcast on local television and radio channels with an advisory from the emergency and healthcare authorities. We will provide showers and uncontaminated clothing for the evacuated people, and open community reception centers, or CRCs, where people will have their exposure level checked and for screening for medical treatment. The screening will involve an interview. The interview will establish the distance and direction of the person from the explosion center, the means of the exposure, such as whether it was external through the skin, or internal as in inhalation or ingestion, and the length of time exposure. The screening will also include a determination of the radiation absorbed by the body. We will then create task forces to determine how to move forward as quickly and as efficiently as possible with the clean up and remediation."

After considering what the chairwoman had said, the president replied, "You mentioned contaminated clothing. I seem to remember reading that alpha particles can be stopped by clothing and beta particles can be stopped by walls. So why should we be worried?"

"Indeed alpha radiation is the least dangerous in terms of causing radiation sickness as it is mostly stopped by the skin, and is most dangerous only when inhaled or ingested. Beta radiation is often stopped by walls, as you correctly mentioned, but it can penetrate through the skin, and cause radiation sickness."

"What are the damage estimates, economic or otherwise?"

The chief of staff already had the figures. "With zero prior experience it is hard to estimate the economic damage accurately. Taking into account the direct damages in Manhattan, the immediate and long-term loss of lives, and the impact throughout the economy in addition to health care costs, loss of productivity, collapse of the New York Stock Exchange, and so on, some suggest the damages will be between several hundreds of billion dollars to even more than several trillion dollars."

"So what is being done to stop this dirty bomb from going off?"

"Mr. President, the FBI is using all their New York field office resources, and is even bringing 200 more agents from headquarters to help out. We have pretty good intel, and the FBI director is telling me they have some very good leads. He is optimistic they can catch the terrorists before the bomb goes off."

The president gathered his thoughts and drew the meeting to a close. Again the image of Sisyphus flashed in his mind as he thought of the recurring threat of terrorism. "Tell the FBI they can have any resources they need, and to coordinate with all federal agencies to stop this from happening."

Questions

1. What is the United States Nuclear Regulatory Commission?
2. List and describe common applications and uses of radioactive isotopes.
3. What is the difference between a nuclear bomb and a dirty bomb?
4. "The half-life of iridium-192 is 74 days, so complete city blocks might be uninhabitable for years." Explain this statement.
5. What are the decay channels of ^{192}Ir?
6. What is an electron-volt (eV)? What is a mega-electron-volt (MeV)? What kind of processes are typically measured in the former unit, and what kind of processes are typically measured in the latter unit?
7. If the initial amount of iridium-192 produces radiation at 1,000 times the safe level, how long will it take before radiation levels drop below the safe level?
8. Cobalt-60 decays to nickel-60 via β^- with a half-life of 5.27 years. A pure sample of cobalt-60 is prepared, with no contamination of other isotopes. After 5.27 years, what is the ratio of cobalt-60 to nickel-60 in the sample?
9. An initial sample of iridium-192 is prepared pure, with no contamination of other isotopes. After a certain amount of time, one finds that the sample includes 4.4% osmium-192. How much time has passed since the initial sample was prepared?
10. Imagine you had the good fortune to find a meteorite in your backyard that appears to be a piece of material from the early history of the solar system. Quantitatively, how would you expect its ratio of potassium-40 and argon-40 to be different from that of other rocks in your yard? Explain why. The half-life for the decay of potassium-40 to argon-40 is 1.25 billion years.
11. You are analyzing Moon rocks that contain a small amount of uranium-238, which decays into lead-206 with a half-life of about 4.5 billion years.

a. In one rock from the lunar highlands, you determine that 55% of the original uranium-238 remains; the other 45% decayed into lead-206. How old is the rock?
b. In a rock from the lunar maria, you find that 63% of the original uranium-238 remains; the other 37% decayed into lead-206. Is this rock older or younger than the highlands rock? By how much?

12. What is radiation sickness? What are the common symptoms of radiation sickness? Of the three types of radioactivity (alpha, beta, and gamma radiation), which is the most dangerous in causing radiation sickness?
13. What are the federal guidelines as to the maximum level of radiation that a person can be exposed to? How does that level compare to the normal exposure to background radiation, and to the amount of radiation absorbed in a CT scan?
14. Some have suggested that a better name for this story would include a question mark, such that it would read "The Never-Ending Contamination?" Argue for or against this suggestion.

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