A SUPER ANALOG COMPUTER FOR EVALUATING THE SAFETY OF BURIED RADIOACTIVE WASTE

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As I see it, the nuclear establishment is hooked on digital computers. Everything from design of equipment to safety evaluation of systems comes out of complex computer codes, understood by very few and relied on heavily by everyone. Careers are built on development of a computer code, and there have been important consequences when the developer of a particular code became unavailable.

In general this situation is worrisome because reliance on codes seems to be a substitute for understanding, and without understanding you don't recognize what is included and what is left out. Errors can be, and have been made in codes, but even without them, grossly incorrect conclusions can easily be drawn.

This situation is especially troublesome in the case of safety analyses on buried waste. The geological problems are extremely complex, and no model even begins to include all the complexity, whereas a digital computer program is a marvellous instrument for covering up neglect of complexities. Their creators expend great effort and write thick documents on some of the complexities they know how to handle. They include such things as variations in waste generation rate with time, radioactive transformation in transit, and three dimensional transport, and they follow the behavior of many dozens of radioactive species. One tribute to the complexity of these codes is that there are several of them in existence, but none of their patrons pays attention to, or probably even understands, the other codes; some give very different results than others, but these differences are seldom even commented upon, let alone understood. Under pressure to produce results from their expensive projects, code developers use data which are highly unreliable or even known to be wrong. For example, they use leach rates obtained from laboratory experiments although these are widely recognized to be wrong by many orders of maginitude when applied to buried material leached by ground water. They ignore a multitude of effects that are known to be very important because we don't know enough about them. For example, the wide variety of rock types encountered and even the variation in physical and chemical properties of a given rock type, rock fracturing and fracture sealing, variations in pH and Eh of ground water with posititon and with time and the drastic changes in chemical behavior these imply (in fact they ordinarily completely ignore chemical reactions), variations in ground water flow patterns with time on both short and long time scales, changes in climate and surface hydrology, effects of earthquakes, and probably many other factors whose importance we don't understand or appreciate. Improvements in the handling of the complexities we do understand in no way compensate for the omission of even a single one of the many complexities we don't know how to handle.

In summary I regard most of the past use of digital computer programs for evalutating the safety of buried waste to be largely a waste of time, effort, and money -- a sacrifical offering to the computer code God that the nuclear establishment worships. Worse than being useless, it provides improper appreciation of the problems and can be dangerously delusive. False information can be much more dangerous than no information at all.

At this point you must be asking what I have to offer as a substitute. Fortunately, I do have something which, it seems obvious to me, is infinitely preferable -- namely an amazingly efficient <u>analog</u> computer. I recognize that there is widespread prejudice against analog computers in favor of digital computers, but I hope I can ask you to rise above this prejudice. My analog computer offers a cure for every shortcoming I have attributed above to the digital computer codes. It treats leaching as it actually occurs in rocks. It takes into account all the geological, lithological, chemical, hydrological, climatological, and seismological variations in both space and time. It is extremely cheap to obtain and operate this analog computer -- in both cases the cost is <u>zero</u>, and it is readily available to everyone. To some people,the fact that it is cheap implies that it is worthless. Perhaps they will be relieved if I mention that the cost to reproduce this computer is far beyond the means of even the U.S. Treasury. Only God himself is capable of reproducing it.

The analog computer I refer to is actual rock in the actual ground. We simply use actual rocks as the analog of buried waste. The analog of every other participant in the analysis is itself, which is the reason why it is so complete and accurate, far more complete and accurate than we can even appreciate. For example you might ask, "Are earthquakes taken into account with their proper probability and time distributions?" Of course they are, as actual rocks experience these earthquakes. The same answer applies to nearly any other question that can be raise.

The question I am most often asked about my analog computer is how do I know that actual rock is a suitable analog for buried waste. This is, of course, the weak point in the use of my analog computer. However, I hasten to point out that on this point my analog computer is every bit as good as the digital computer codes. They also treat buried waste the same as actual rock. There is one exception to this -- they usually use leach rates measured in the laboratory for waste forms. But in this they are absolutely wrong, as I have explained in lengthy detail in a recent paper[1]. In fact laboratory measurements of leach rates for actual rock are similar to those for the waste forms, but they are orders of magnitude different from the leach rates of this rock in situ due to ground water. This difference is widely recognized and understood by people in the laboratory leach rate testing business.

It has been argued that leaching of waste in the ground would be very different from leaching of natural rock because the waste is a "foreign material", not in equilibrium with ground water and the surrounding rock. But this equilibrium is basically a surface phenomenon and is, for the most part, rapidly reached after removal of only a few microns of the original surface of the waste form. As ground water leaches away the surface, it simultaneously precipitates out a highly insoluble silicate which rapidly builds up as a coating on the surface that is in chemical equilibrium. Further leaching can only occur by diffusion through this coating, a very slow process. With regard to waste elements being "foreign materials", the same is true of any waste elements in natural rock. But there is no evidence that these trace elements leach out of rock and appear in ground water at a higher rate than comparable major elements. The ratio of abundances in ground water and in rock is about the same for U and Th as for major metals like Fe, Al, and Mg, and this ratio is lower for Li and Rb than for their chemical analogues Na and K.

Up to this point I've concentrated on explaining why my analog computer is superior to the digital computer codes. I am absolutely convinced of its superiority and would be happy to argue it with anyone interested. The next, and more important question is, "How good is this analog computer?" But before going into it, let me explain how it is used and give some of its results. There are many ways to use it, but I will describe one example of its use for high-level waste and then one example for low-level waste, beginning with the former.

Suppose we want to use it to determine the release rate through ground water of an atom of <u>average</u> rock <u>in</u> an <u>average</u> aquifer at 2000 ft depth[1]. Treating average rock and an average aquifer gives a feel for the generic problem, although assuming that it is submerged in an aquifer is clearly a conservatinve assumption if this is to be an analog of buried waste.

An average aquifer at 2000 ft depth has a total length of about 100 km, the rock has about 10% porosity, and the flow rate of water through it is about 100m/year (1 ft/day). Note that there is no need for high accuracy in any of these numbers, since our results are roughly proportional to them -- there are no exponentials, small differences between large numbers or any such complication that magnifies errors. From these numbers it is straightforward to calculate the quantity of water released out the end of this aquifer each year per square meter of cross sectional area (presumably it is released into a river). There are many chemical analyses available for concentrations of various materials in ground water[2], and from them and the quantity of water released each year we can calculate the quantities of each rock material removed (in kg/yr) by the aquifer water going through the rock. This is listed in Col. 3 of Table 1.

We also can easily calculate the total quantities of these materials in the rock traversed by the aquifer. This is just the total quantity of rock in a volume $1m^2$ in cross section and 100km long, multiplied by the concentration of these materials in average rock[3]. The result of this simple calculation is shown in Col. 2 of Table 1. The final column of Table 1 is the ratio of Col. 3 to Col. 2 listings which is just the fraction of each material released from rock into rivers. We see that these numbers are of the order of 10^{-8} -- one part per hundred million is released each year into rivers.

I consider this simple result to be more significant and meaningful than all results obtained from digital computer codes combined. In fact, if anyone really believes in his code, I challenge him to calculate this number -- if his code is useful, it should be able to do so. After all, the codes are every bit as applicable to average rock as they are to buried waste. In actual fact, every one of these codes would estimate the release rates to be orders of magnitude higher than the numbers in the last column of Table 1. That proves that they are wrong; I would like to use a more charitable word, but I don't see that it would be justifiable to do so.

My second example is applicable to buried low-level waste[4]. Here we are dealing with materials in soils and soil chemistry, so as our analog to buried low-level waste materials we choose material of the same chemical element occurring naturally in soil. Suppose we ask our analog computer to estimate the probability per year for transfer of various chemical elements from soil into humans. This is a straightforward problem: we know how much of each element is in soil, and we know how much of each element is ingested annually by humans. The ratio of these two is the required transfer probability. For example, if we consider material in the top 12 meters of soil for Fe it is 8×10^{-11}/yr, for Ni it is 1.7×10^{-9}/yr, for Sr it is 1.6×10^{-9}/yr, for Pb 1×10^{-8}/yr, for U it is 2.2×10^{-10}/yr, etc. For elements that do not occur in nature, like Tc, Pu, and Am, it is easy to make estimates based on behavior of other elements in the same column of the chemical periodic table of elements.

This method was used[4] to analyze the safety of the waste inventory buried at Maxey Flats (KY). In addition to direct transfer from soil into food, transfer into rivers and thence into drinking water was considered, as was suspension as dust in air followed by inhalation by humans. It was concluded that if all of this waste became uniformly distributed through the ground and no precautions were exercised, the total number of fatalities integrated over the next 10 million years is still less than <u>one</u>.

Again I challenge the digital computer codes to calculate the transfer rate for various elements of average soil into humans. If they cannot do that, they must be useless.

Now let me return to the high-level waste problem and consider the really important question -- how good is the result given by our analog computer? If the result is valid, that the transfer probability per year for an atom of waste into a river is only 10^{-8}, it can be shown[1] that the total health effect of buried high-level waste integrated over time is only about 0.001 fatalities/GWe-yr.

Since the comparable effect for wastes from coal burning is tens of thousands of times larger, we must surely be wasting our time worrying about nuclear waste. Thus our question is a crucial one -- how good is the result given by our analog computer?

This boils down to the question of how good an analog average rock is for buried waste. There are basically two ways in which buried waste is less secure than average rock: (1) shafts and corridors have to be constructed in order to emplace it, and (2) it contains an internal source of heat. If one is to worry about the security of buried waste, these are the things he should worry about. To the best of my understanding these questions boil down to (1) can the shafts be securely sealed?, and (2) does the heat crack the rock or have important effects on the chemistry? I hope I am not being overly redundant in pointing out that the digital computer code safety evaluations contribute nothing to the answers to these questions. They have to be answered by good old fashioned scientific work developing an understanding of the problems. To the best of my knowledge, there is a high degree of optimism among those working on the problems of shaft sealing and rock cracking, and leach resistant casings seem to provide an answer to the effects of heat on chemistry by delaying the time when the chemistry starts until after the heat is gone.

This evaluation cannot be complete until we also consider ways in which the buried waste is more secure than the average rock we use as its analog, and there are several such ways. In the first place, the analog rock was assumed to be in the water table, permeated by water which is part of a typical flowing aquifer, whereas the waste is in a water-free region and in a rock formation essentially impermeable to aquifer flow. In the second place, the waste is in a carefully selected geological environment presumable free of rock fracturing problems, whereas the analog rock is in an "average" geological situation with an average amount of rock fracturing. In the third place, the waste will (I hope) be enclosed in a highly leach resistant casing and surrounded by a judiciously chosen back-fill material -- these are luxuries not available to our analog rock. In fact, the leach-resistant casing may provide a complete back-up system by itself just in case there is rock fracturing and even if everything else fails. In the fourth place, the waste repository will be monitored and escaping radioactivity is easy to detect in plenty of time to take counter-action if the remote possibility of failure should materialize.

In view of the highly favorable results produced by our analog computer, and of all these advantages of buried waste over our analog rock, it seems to me that as soon as the shaft sealing people cna assure us that they can effectively seal the shafts, and the rock mechanics people can give us assurance that the heat will not cause extensive rock fracturing, and the casing people confirm that their casings will perform as advertised, from the technical stand-point we are ready to proceed.

REFERENCES

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3. R. M. Garrels and F. T. MacKenzie, "Evolution of Sedimentary Rocks", W. W. Norton (New York) 1971.

4. B. L. Cohen and H. N. Jow, "A Generic Hazard Evaluation of Low Level Waste Burial Grounds", Nuclear Technology, Dec. 1978.

TABLE 1

Estimate of Fractional Removal per Year of Materials from Deep Rock by Groundwater

(Based on a 1-m^2 cross-sectional area of a 100-km-long aquifer with water flow velocity 100 m/yr through rock with 10% porosity. Rock compositon is from Ref. 3, p. 245, and groundwater composition is estimated from Ref. 2.)

Element or Ion	kg in Rock ($\times 10^6$)	kg/yr in Water	Fraction Removed per Year ($\times 10^{-8}$)
SiO_2	150	0.2	0.13
Ca	15	0.3	2
CO_3	18	1.5	8
Mg	3	0.03	1
K	3	0.02	0.7
Fe	9	0.003	0.03
U	8×10^{-4}	3×10^{-4}	0.3