DR. RODNEY LEE AAMODT,

Scientific Advisor to the AEC Director of Nuclear Operations

DIRECT EXAMINATION BY MR. YANNACONE:

Q. Dr. Aamodt, do you want to give us your full name and address, for the record.

A. Rodney Lee Aamodt, Santa Fe, New Mexico.

Q. What is your present job title?

A-I am staff member at the Los Alamos Scientific Laboratory.

Q. And what is your relationship, if any, with Project Rulison?

A. I am the Scientific Adviser to the Director of Nuclear Operations.

Q. Who is the Director of Nuclear Operations?

That is Mr. Thalgott.

Q What are your duties and functions with respect to Mr. Thalgott?

A. There are many times in the performance of his duties where he needs to make a judgment on a scientific question.

Q. Such as?

A. Questions of predictions of ground motion, for instance. And in cases like that, I try to get the best scientific advice together that we have available, and to come up with an appropriate interpretation of the facts.

Q. Do you want to briefly summarize your educational and professional background for us.

A. Graduated from the University of Utah in 1947, in physics, and from the University of California in 1951, Ph.D. in physics.

Q. Which University of California?
A. At Berkeley.

Q. How long have you been associated with Los Alamos?
A. Since December of 1951.

Q. And what is your job title at Los Alamos?
A. I have been Group Leader in the Weapon Test Division.

Q. And you have been that up until the time you became consultant here at Project Rulison?
A. Shortly before that, about maybe two years ago.

Q. What, if any, responsibility do you have with respect to the safety of Project Rulison?
A. I have been responsible to put together the effects evaluation document that was used to delineate the safety problem for the shot itself.

Q. Did the effects document that dealt with the shot itself deal with anything other than potential seismic hazard from the shot?
A. Yes, it dealt with the radioactivity also.

Q. And what kind of radioactivity was forecast for the shot?
A. We forecast that there would be none.

Q. And at the present time, following the shot, have you made• measurements to see whether your forecast was accurate?

A. To my knowledge, it is accurate. I have been notified almost daily, and recently weekly, as to the levels at the wellhead.

MR. EARDLEY: I think it should be clear, Vic, he is talking now about radioactivity on the surface, not in the cavity.

MR. YANNACONE: Oh, yes. We assume that the cavity is a bit warm in a radioactive sense.

Q. (By Mr. Yannacone) Are there any estimates, by the way, available of what the relative encapsulated amount of radioactive material is?

A. I think it is very close to this list that was furnished by Campbell 40 kiloton device which is among your papers somewhere.

Q. The material that will be flared at the wellhead will consist of some radioactive nuclides, will it not?

A. We expect it to, yes.

Q. Have you, in the regular course of-your professional association with Project Rulison, investigated, studied, or otherwise dealt with the proposed flaring?

A. I have.

Q. And would you summarize for us the extent or your work with the flaring.

A. Well, I am on this Technical Committee which con- siders-the method of evaluating the cavity and the effects of the detonation with regard to gas flow and so on.

Q. Let's cut right through the heart of the matter. Are you in any way responsible for evaluating the safety of the proposed flaring recommendations?

A. I feel that I am.

Q. Is there anyone else that is so responsible, in addition to you?

A. The final responsibility, of course, is Mr. Thalgott's. You want other people beside him?

Q. The final responsibility **is** Mr. Thalgott's?

A. In the field, yes.

Q. Now, if I recall Mr. Thalgott's last testimony this morning, Mr. Thalgott indicated that he had no independent freedom of action with respect to activities at the wellhead other than determining whether or not the proposed action was within certain standards that were set down by others, both above and below. Is that right?

MR. EARDLEY: Well, I object to that. He may not have listened to the testimony. He may not know whether your paraphrasing of it is correct or not.

Q. (By Mr. Yannacone) Dr. Aamodt, were you here this morning when Mr. Thalgott testified?

A Yes, I was.

Q. Did you hear the last three or four questions before lunch?

A. Yes, I did.

Q. Was that essentially the substance of Mr. Thalgott's testimony?

A. I might prefer to rephrase it.

Q. Please do.

A. He said that he could take whatever action was necessary to protect public safety.

Q. And this protection was within certain guidelines, right?

A. Within, above, and below.

Q. I will rephrase the question. The determination of what was or was not safe was based upon guidelines which he did not participate in the making of, is that correct?

A. That is correct.

Q. Did you participate in the making of them?

A. No.

Q. Did you participate in any way in the determination of the safety procedures or the evaluation of the potential hazard from the flaring of the radionuclides from Project Rulison?

A. Yes, I have.

Q. And tell us the extent of that evaluation.

A I called all the contractors who make calculations that have to do with public safety together. We held a two- day meeting in Las Vegas.

Q. Which contractors were those?

A. People like ERC, Isotopes -- you got the list from

Q. Well, I want to know which ones were at the meeting.

A. Public Health Service.

Q. Was that Dr. Carter?

A. He wasn't in town at the time. He was represented there.

Q. Anybody else?

A. Battelle Memorial Institute.

Q. Who represented Battelle?
A. I don't recall their names.

Q. The gentleman that testified at the earlier hearing?
A. He was there. Glenn Fuller was there, yes. There were others.

Q. Anybody else?
A. And I think there was a gentleman from the Livermore Laboratory who sat in at times on the meeting, too.

Q. That's the University of California Lawrence Radiation Laboratory?
A. Right.

Q. Now, how long did this meeting last?
A. About two days.

Q. Will you summarize briefly what was considered.
A. Predictions of levels of radioactivity in the air, in the water, in food.

Q. From what?
A. From flaring and from whatever kind of circumstances we could imagine that might present a hazard to the public, conceivably.

Q. And approximately what values did you come up with as potential atmospheric or water contamination?
A. I guess I could only say that there were no cases that we could imagine where we could foresee any manner in which the public could receive more than the guidelines.

Q. Which guidelines?
A. These of 0524, 2A and 2B.

Q. Well, 2B doesn't specify a level, does it? 2B is the

procedural requirement, isn't it?
A. Let's look at it and see.

Q. This is a poor copy, but you may have it.
A. Right, 2A is what I should say, instead of 2A and 2B.

Q. Now, with reference to 2A, you made an evaluation that the total flaring as proposed would not exceed the annual dose or dose commitment in rems indicated in Appendix 0524, Subdivision 2A, right?
A. That's right.

Q When you made this determination, did you do it solely from the amounts and levels of ionizing radiation present in air and water as a result of the flaring?
A. No.

Q. What did you evaluate it on?
A. On our procedures for taking action during the operation.

Q. 1'm afraid we don't understand each other. With respect to the flaring of radionuclides, a certain quantity of natural gas, containing certain radioisotopes, among them tritium and krypton, will be flared to the atmosphere, is that correct?
A. That's correct.

Q. To be more specific, tritium 3 hydrogen or krypton 85.
You made an estimate as to how much of each of these radioisotopes would be released, based on the proposed volume of gas to be released, correct?
A. We actually were more conservative and assumed that all of these products would be released.

Q. When you say "all," how much is "all"?
A. We have an estimate at the moment of about 10,000

curies of tritium and rather close to 1,000 of krypton.

Q. 85?

A. 85, yes.

Q. Now, you assumed that all of these would be released, correct?

A. Yes.

Q. Over how long a period of time?

A. Well, we considered time periods as short as twenty- four hours for the total release.

Q. And what did you do next in your evaluation?

A. We looked at the kind of concentrations that this might give rise to in the air.

Q. And in the water?

A. It's a little more difficult in the water, because there are many circumstances which will — you know, rainstorms and things like this, which --

Q. Let's stick solely to the air.

A. All right.

Q. Now, with respect to the air, what did you estimate the concentrations would be?

A. You are interested, I would guess, in the dose rather than the concentrations?

Q. No, I am interested in the concentrations first. Then we are going to ask you how you arrived at the dose.

A. I don't remember the concentrations, because we were not concerned with the concentrations, but with the dose to people.

Q. Can you arrive at the dose without knowing the concentrations?

A. Quite readily, if you have someone to calculate it for you.

Q. Please outline, without doing actual figuring, the method of converting from total available quantities of ionizing radiation, such as 10,000 curies of tritium, into a dose?

A. You just integrate the concentration over time and realize that the concentrations in the table there give .5 R to people, so you divide those concentrations by three, then you integrate them for a one-year period and divide that into your earlier number.

Q. Now, you are assuming that the concentrations given in the table designated Annex A of AEC Appendix 0524, yield a body dose, whole body dose of .5 R?

A. Let me look and see what you are calling -- Table 2?

Q. And that dose, which for tritium is two times 10^{-7} microcuries, which is two-tenths of a picocurie, per milliliter of air, will yield a dose of half an R, is that correct?

A. I think that's correct. You mean that dose there, at least, that is listed in there.

Q. Now, when you say".5 R," you are talking about .5 R, the R being "roentgen unit," right?

A. These are biological dose --

Q. Now, just a moment, Doctor. Isn't it a fact that when you say "R," a single R, you are referring to roentgens, you are not referring to rems or rads? Now, do you mean .5 R or .5 rem?

A. I mean .5 rem.

Q. Now tell me, Doctor, how do you convert absolute quantities of radionuclides or ionizing radiation in curies to rems?

A. Knowledgeable people who work in that field do experiments and prescribe how that's done. I can tell you also the details if you want, but you know those, too.

Q. Tell me for the record the details of how you get from curies to rems.

A. Well, you have to choose the effect that you are concerned with, let's say.

Q. What effects are within the realm of choice?

A. For instance, longevity.

Q. Of what?

Of whatever it is that you are measuring this on.

Q. This is species-dependent, isn't it?

A. Yes.

Q. And "r-e-m" means "roentgen equivalent man," right?

A. Right.

Q. Have these studies ever been done in man?

A. I can't speak very extensively, because this is not my field at all.

Q. Was there anyone on the team that did the evaluation of the proposed flaring, the safety evaluation of the proposed flaring for Project Rulison, that is knowledgeable in this field?

A. This work has been done already in preparing these tables.

Q. Dr. Aamodt, those tables allege to relate concentrations of radiation in air and water to rem in terms of annual dosage or dose commitment on an annual basis, is that correct?

A. That is my understanding.

Q. And to the best of your knowledge, then, you don't know the mechanics of how this is done, do you?

A. I certainly don't intend to try to let an uninformed opinion supersede these which are done by the most qualified people in the country.

MR. YANNACONE: That is only your opinion. I move that this be stricken.

Q. (By Mr. Yannacone) Doctor, are you qualified to evaluate the credentials of people that allegedly are so qualified to make that determination?

A. Not very well, other than any citizen.

Q. You take it as gospel faith, don't you, that that amount of ionizing radiation in the atmosphere: from that particular radionuclide, will be equal to or less than a quantity of rems, is that right?

A. I assume that the best qualified people that were available have made that kind of decision. Now, that doesn't call for gospel faith.

Q. Doctor, are you qualified to evaluate the competence of the people that did make that decision?

A. The fact that a man is on the National Radiation Council, for instance, or these other eminent committees, is considerable evidence that he is accepted in the field.

Q. Doctor, isn't it a fact that by relatively uncomplicated, unsophisticated calculation, you can convert absolute quantities of radiation in terms of curies, micro- curies, or picocuries, per unit volume of a medium such as air and water, to R or rads, roentgens or rads?

A. It is not quite as simple as you have to know all of

•

the ionization potential, the excitation levels of the material in which this dose is appearing and be able then to talk about the total energy deposited, and if this is not-extremely high level so you can measure a temperature, then it is not an easy conversion.

Q. Now, Doctor, aren't the absolute levels o ionizing radiation in terms of curies directly relatable by simple mathematical relationship, or don't they bear a simple mathematical relationship to the dose we call "roentgen" and the dose unit we call "rad"?

A. It is rather simple for the roentgen, because it was defined for air, but it is not simple for rad.

Q. All right, but it is still a direct conversion that involves simply manipulating the mathematics of certain figures, right?

A. It calls also for knowledge of the molecular excitation levels and so on.

Q. Of what?

A. Of the material in which this dose is being absorbed You see, for R, we talked about air and now we know what we are talking about there; it is so many ion-pair.

Q. Doctor, I am talking about the amount of radiation measured in curies per unit volume of air. Now, we can convert that relatively simply to roentgens, can't we?

A. That's right.

Q. And we can convert roentgens to rads by the multiplication of the appropriate factors, can't we?

A. Not quite, no.

Q. What is the difference then? What else do you have to do, Doctor?

A. Well, you have differences in the gamma ray energy and then the stopping power of various materials. If you are stopping in a heavy material

Q. Doctor, we are talking about air.

A. Oh, then air -- yes, I think that you can quite readily.

Q. Right. It is a relatively simple relationship, is it not?

A. That's right.

Q. But you can't convert from roentgens, rads, or curies per unit volume of air, to rem, without relying wholly and entirely upon certain experimental and empirical data, isn't that a fact?

A. Yes, you —

Q. Isn't that a fact, Doctor?

A. What do you mean by "empirical" as opposed to "experimental"?

Q. As part of and in explanation of "experimental."

A. "Experimental" is "empirical"?

Q. Strike the word "empirical." Let's just take it with "experimental."

A. I think I agree, yes.

Q. It is a fact?

A. Yes.

Q. And the rem is a rather subtle or, we might even say, slippery unit of measurement, compared to the rad or the roentgen?

A. It is an attempt to make the dose more realistic when you are talking about people. It may not be better, but it is a better measurement than the rad.

Q. Isn't it a fact that the rad and the roentgen, when used as a measure of ionizing radiation, are readily convertible to units of energy, such as ergs?

A. Yes, that is a definition.

Q. Joules, even?

A. Yes.

Q. And isn't it a fact that the effect of ionizing radiation on tissue is a function of the energy of the ionizing radiation?

A. I think that is correct.

Q. And isn't it a fact that the effect of radiation on tissue is a function of the work in the classic energy-over-distance sense that the ionizing radiation performs at the cellular level?

A. Not very well -- it isn't a very general truth.

Q. What is the general truth, then?

A. Well, you can cause dislocations of atoms, and this is different than dislocating electrons.

Q. In other words, then, the mode of action of ionizing radiation in the human cell proceeds at at least two levels, the electron level and the atomic level? And this behaves in a manner that is essentially obedient to the rules of statistical mechanics on a cellular level, isn't it?

A. Would you define what you mean by the cellular level? We are talking about electron level and the atomic level, and now.

Q. Within your individual cell, the basic unit for nuclear ionizing radiation purposes, we can deal with electrons, nucleons and the atom itself, right?

A. Right.

Q. And the larger unit would be a molecule, perhaps?

A. (The witness nodded affirmatively.)

Q. When we talk about "at the biological level," we are talking at the cell level, generally, as a basic unit?
A. Yes.

Q. And when we are talking about the components of the cell,,,we are talking about certain large macro-molecules, such as DNA, more commonly known as deoxyribonucleic acid, and RNA, and certain polypeptides, and certain other large molecules, some of which have yet to be duly identified, right?
A. You said it very well.

Q. MR. EARDLEY: Did you get an answer?
Q. (By Mr. Yannacone) Is it right or isn't it right?
A. I am not qualified to say that it isn't right. It sounded correct to me.

Q. You are not qualified, then, to determine the biological effects of ionizing radiation, are you?
A. Certainly not.

MR. YANNACONE: I have no further questions. Thank you.

EXAMINATION BY MR. RICHARD D. LAMM:

Q. Could you tell us again what the half-life of tritium is?
A About 12.3 years.

Q. Earlier in the testimony, you were here present in the room when the previous witnesses, particularly Mr. Thalgott, said that the wind was a factor in deciding on the detonation time?
A Yes, sir.

Q Does the wind have any factor with regard to the flaring time?

A. It certainly will determine where the radioactivity goes — the wind at the level to which this flared gas rises.

Q. Are you familiar with the different potentials, for instance, with regard to the dispersion of the gas?

A. Yes, I think so, if I understand your meaning.

Q. Well, in other words, I assume that what you are saying is that the distance of the gas being dispersed would be somewhat of a factor of the way the wind is blowing and the velocity of the wind blowing?

A. And its turbulence and the presence of inversions, and whether there is vertical mixing — if there are wind shears between different layers. All of these things are required to predict the levels.

Q. Have you in your determination computed a maximum possible dispersion area of the flaring.of the tritium?

A. We usually try to take the minimum possible, in order to concentrate the radiation, so that we can decide if it is a hazard. The maximum possible, I suppose, is just in all directions. And perhaps you could say a little more about what you are interested in?

Q. Well, I assume what you are saying, then, is that when you are taking it in terms of maximum area, you are talking about a dilution of the tritium, which essentially reduces its effect to nothing in various areas?

A. That is right.

Q. And so, for purposes of your safety testing, you use a small area and a small area of time?

A. (The witness nodded affirmatively.)

Q. And that is why you gave us earlier the 24-hour figure?
A. That's right, because it gave the highest doses on that -- the wind doesn't have time to shift very much in such a time, whereas if it came out over a longer period of time, you'd have winds from a number of directions, and then the dose at some given distance would be less.

Q. When you were talking in terms of the 24-hour period, that was the smallest period of time which you figured, made your computations on, is that right?
A. Yes.

Q. And did you figure that, then, for various wind levels and velocity levels?
A. We did, yes, sir.

Q. How many different alternatives did you compute in this one 24-hour period?
A. I am not entirely sure. I know of at least five, I guess.

Q. And those five differentiated by the factors of wind velocity, inversions, turbulence?
A. In that way, and also in the height at which the gas was released.

Q. And do you recall what height, the variations there were in those computations?
A We did as low as seventy feet, and then, after getting a better feeling for what this real problem was, we took numbers between 100 meters and 1,000 meters; 300 meters was another number.

Q. Now, in terms of the Federal Radiation Standards, what were your various computations, the results of your various computations on your one 24-hour period for your various factors considered?

A. The number that I can recall right now is about 1/100th of this .17 rem at the distance of the nearest people, five kilometers.

Q. The distance of the nearest person or people, which you figured to be five kilometers?

A. Permanent residents, I should say.

Q. When you mention considering feasible alternatives, what different methods did you consider at all and disregard as unfeasible?

A. We thought of pumping the gas into a hole in the ground; as was suggested by one of the counsel, I believe, yesterday. We discarded this as being just exactly the kind of thing that caused the Rocky Mountain Arsenal problem.

Q. You explored flaring without ignition or igniting the gas?

A. I have been told this is unsafe by the industrial people, and I believe it is against the law.

Q. Do you know, of your own knowledge, what law that was you were told of?

A. I know — well, very seldom do I know law of my own knowledge, but I have been told that New Mexico does have such a law that does not allow it; that it was not safe, from one of our consultants in the petroleum industry, and his opinion was that Colorado had a law that also would prevent it.

Q. Was that the reason, then, you discarded that as unfeasible?

A. Yes.

Q. That there might also be an explosion of the methane gas?

A. It was really the explosion hazard that --

Q. Did you consider any of the cryogenic methods?

A. The main difficulty with the cryogenic method, if you are talking about separation -- is this what you are asking?

Q. Yes.

A. -- is that the tritium is in the gas itself, it is in the methane, and so you could take some fraction out, but you

Q. Well, if you would burn it, you would reduce – I assume you would then have the tritium in some sort of water that could be --

A. It would be in the form of water.

Q. And then could be separated by cryogenic methods?

A. You don't really need cryogenics, because all you have to do now is get down to the freezing point of water. It is still just enormously expensive. Our rough estimates were that it was over a half a million dollars to set up a plant that could do something like this.

Q. For this particular alternative, then, unfeasibility meant merely a matter of economics?

A. I believe so, because you could consider storage in a very huge volume at atmospheric pressure, again an expensive operation, for one

Q. Well, getting into that one, then, that would be another alternative?

A. Yes.

Q And you disregarded that as unfeasible also?

A. Right.

Q. And the same reasons, because of the economic considerations?
A. Economic and because of the small dosage which you would be buying a very small improvement in the levels of radiation that people are exposed to.

Q. So, in other words, this wasn't purely an economic decision, there was a scientific input into it?
A. That's right.

Q. A comparing of the economic costs?
A. Yes.

Q Now, you didn't yourself figure the economic costs, I assume?
A. I had estimates made by chemical engineers, I guess I should say, at Livermore. They are very rough, though.

Q. Were they were furnished to you in some sort of memorandum?

A. No, just -- I visited there and spent some time with the people and did it on the blackboard.

Q. Do you recall what their estimates were for the various alternatives that they proposed?
A. That we didn't see anything that was under a half a million dollars; and I had a feeling these would get more expensive, even, if we looked at them closer. For instance, to dispose of the water would cost something like $250,000.00 a day, if we were to jell it and then ship it over the road to a disposal site -- just that many barrels and that much jell.

MR. EARDLEY: How much?
THE WITNESS: It's about thirty-one dollars a barrel, it was, to handle this material.

MR. EARDLEY: But I understood correctly $250,000.00
a day?

THE WITNESS: Yes.

Q. (By Mr. Lamm) Did you make a qualification of your answer?

A. Yes, what I was saying was that in addition to taking this water out, you now have to dispose of it, and disposing of it by —to carry it over the roads, the regulations require that it be made into a jell so that it wouldn't leak in case of an accident; and that this process, putting it in barrels, jelling it and transporting it, was estimated to cost about $250,000.00 a day during the high rate flaring.

Q. How much gas do you feel has to be released from this cavity to accurately measure the amount of gas that this well stimulated?

A It can be as low, according to my estimates, as 10 per cent of the radioactivity and it can be as high as about 94 per cent of it.

Q Under present plans, do you have a percentage of radioactivity release under your present plans?

A We have made it the highest numbers, but if it is possible to do it with lowest numbers, we will certainly do it. If the rate of inflow is low, for instance, then we can release much less radioactivity.

Q. Well, did you have an opportunity to study at any point the answers to the interrogatories?

A. I think I am familiar with those that are concerned with the flaring periods and the amounts.

Q. Referring, then, to Dr. Seaborg's answers to his interrogatories, particularly the calibration tests, the short-term high flow rate testing, the intermediate-term, lower rate flowing, and the long-term flow rate, in his answers, are you familiar with the various numbers that he used in there?

A. I am, yes.

Q. Do you have an estimation of what percentage of the radioactivity is to be released, under these answers?

A. At the end I believe they say 500 to 1,000 total of that's 500 to 1,000 million standard cubic feet. And at the level of 500, I estimate that about three-quarters of the radioactivity will be released, and at the thousand level, it's about 94 per cent.

Q. Then you have made calculations with regard to testing the amount of gas created by the nuclear device, that would be as low as 10 per cent of the radio- activity?

A. Yes, I have. And this — for instance, if the fraction of the tritium that were in the form of water were as high as it was in the case of Gasbuggy, something like 95 per cent -- and this is a thing we will know better, of course, as soon as we get a sample then we would reduce these estimates by that number, which would make this 1,000 million standard cubic foot equate to about 10 per cent of the activity in the cavity.

Q. If I understand your answer -- and correct me if I'm wrong what you are saying is if the gas found in the Rulison cavity is at the same tritiated level as was present in Gasbuggy —

A. The same fractional distribution between gas and water.

Q. All right.
A. We assume here, you see, that it is all in the gas, and that is the conservative assumption that makes the dose highest.

Q. I understand. Then the highest figure used here, the 1,000, —
A. Yes.

Q. Would, in effect, it not be the 94 per cent level as computed?
A. No, it could be then the 10 per cent. And then, of course, with other conditions like a low input rate, so we didn't have to flow at such a high rate, the number could be still smaller.

Q. Is it your intention, in your various testing alternatives, then, to test this amount of gas stimulated at the very lowest possible method, to get the computation?
A. Yes, sir.

Q. Going back to the idea of the figure that you gave in your answer with regard to freezing the tritium out of the gas, can you give me the name of the person who gave you the estimate of the half million-dollar figure?
A. Let's see if I can remember. I can give you the name of the man who could tell you his name, the one who --

Q. That would be good enough.
A. Wayne Woodruff -- that was my contact there.

Q. Would you identify him more specifically.
A He is a member, staff member of the Livermore Radiation Laboratory.

Q. But to your knowledge, nobody in the Atomic Energy Commission or Austral Oil Company or CER Geonuclear

Corporation has made these economic computations themselves?

A. That is correct.

Q. And so, would it be fair to say that the economics of it is really just a guess?

A. I think that is fair, yes.

Q. It could be perhaps as high as a million dollars, or it could be as low as $200,000.00, for all you know.

A. For the plant itself?

Q. For the method of separating.

A. Yes, just the method of separating, leaving you still with the problem of disposing of the water that you collected.

Q. Would it be fair to say that perhaps the method would be as low as $100,000.00, really, for all we know?

A. I doubt it very much. I don't think it could be as low as two hundred thousand.

Q. Dr. Aamodt, can you compute how much water would be present in 500 M.m.s.c.f. [million standard cubic feet]?

A. Yes.

Q. Do you know that from your own knowledge, or can we furnish you with pencil and paper?

A. It is a fairly complicated calculation.

Q. Could you estimate it roughly?

A. Yes, it is close to a number like 8,000 or 10,000 barrels, I think, per day.

Q. This has been done before?

A. Yes.

Q And it has been disposed of through various disposal methods that are well known to the Atomic Energy Commission?

A. It is well known that you have to jell it, for instance, and so if you are talking about the disposal, the answer is yes.

Q. Going back to your previous comment, however, you were talking about 500. The figure that I requested was the total amount of gas to be flared.

A. Yes, sir.

Q. Now, you said in your answer "per day." Your 8,000 barrels is a per-day figure?

A. It is a per-day figure, and I hope it is accurate, for the 20 million cubic foot rate.

Q. I understand. So you are saying, then, that the total amount of barrels that would be in the 500 M.m.s.c.f. figure would be how many barrels?

A. 500 divided by 20, which is 25 times this M.

Q. 25 times the 8,000?

A. Yes. Now, before you use those numbers, I1d really like to give you a better estimate. This will do for talking purposes.

Q. (By Mr. Lamm) In terms, however, of actual investigations on the part, to your knowledge, of the Atomic Energy Commission, there has been no formal investigation made as to the economics of how much it would cost to dispose of the tritium by this method?

A. These numbers that I got on the disposal cost of the water came from a consideration of this method of I mean, they assumed that there is some way in which you could get the water, and then they asked, could we afford to handle this water, and this is where these numbers came from, from Don Hendricks, who is in charge of the Safety Division of the Nevada Operations Office of the A.E.C. ***

Q. (By Mr. Lamm) Actually your answer to that last question, then, is that you determined what would be economical, and how did you figure the economics of this to reach your determination of uneconomical?

A. It was just -- it was such a high number that, looking at the estimates of what the radiation dosage to people would be, it didn't seem to make sense to pursue it any further.

Q. Dr. Aamodt, in effect, in regard to the disposal of the water in case that alternative was chosen, did you give a figure with regard to the cost of disposing of the jelled substance in itself, t e actual disposal only?

A. The cost I gave was for the transportation and the jell and the cost of the barrel.

Q. What was that figure?

A. It was on Gasbuggy, where this was done — at that time it was thirty-one dollars.

Q. A barrel?

A. A barrel. And I would guess that it is from twenty to forty dollars now -- a lower number perhaps because you do it on a larger scale, and a larger number be- cause costs have gone up.

Q. That includes the cost of the barrel and the cost of the transportation and the cost --

A. About eight dollars for the jelling material, I understand, per barrel.

Q. The jelling fluid, the barrel, the transportation, and the disposal?

A. This cost for Gasbuggy did not include any cost for disposal, it just — they took it to the Nevada test site.

Q. The Atomic Energy Commission has its own waste disposal wells?

A. Yes.

Q. And you have them as near as Nevada and as near as Montana, I understand?

A. I am not sure where -- I think these would probably go to a commercial disposal area.

Q. Are you familiar with approximately the price that they charge per barrel?

A. No.

Q. Would one dollar a barrel sound right for the full disposal in itself, not counting

A. I couldn't guess very well.

Q. Why did they use this process of jelling in the Gasbuggy experiment?

A. I am not sure that they did. I think that what they shipped in Gasbuggy was contaminated dirt, perhaps.

Q. You mentioned that the jell -

A. To ship water, you have to jell it, to meet the I.C.C. regulations, I believe it is.

Q. And in terms of that, you mentioned that they had to buy jell for the Nevada -- for the Gasbuggy? You mentioned the test.

A. No, that is part of the cost of doing it if you move just water.

Q. To the best of your knowledge, then, they did not use this method, even in part of the Gasbuggy experiment?

A. Only that they put material in barrels, in suitable form for shipping, and that this is what it cost to do it, in shipping it.

Q. Has there been any exploration or, to your knowledge, contracts let by the Atomic Energy Commission with regard to the other methods of disposing, other alternatives? We talked about storage in tanks, surface tanks.

A. No, I think that you have the extent of -- there is perhaps one more possibility, to provide a storage facility capable of storing the thousand million standard cubic feet and the combustion products from that. And you could consider, if you had that capability, putting that back down the hole after you are through.

Q. If I understand your answer, then, in other words you could take out the gas, store it in tanks, and put the gas back in the same hole as you took it out from, and get your measurement?

A. What he was talking about was-to burn it and then store the water. And first you have to take that out, of course, and then keep the water on site, have a storage facility big enough to take the whole entire operation, and then your last step in the operation would be to pump that water back down the hole.

Q. So, in other words, it is possible to do this, perhaps, without even having to jell it or transport it or dispose of it, by putting it back down into the same hole?

A. But only if you have this storage facility for that much material.

Q. Could you not use the same hole that you have right now, the actual cavity, for the disposal of the same water that you have taken out to measure the cavity?

A. Apparently there would be great difficulty, because of the flowing gas that is coming up — this pipe.

Q. But there are a number of injection methods, with regard to mud and other things, normal in oil fields, as I understand it, that do recycle oil wells, so that must not be a technical problem, and do you know, have you explored that?

A. We have found that the velocities were high enough that if you tried to put the water back down the hole, it would be entrained in the gas and just carried out **again,** if you do this during the high-rate testing or even the lower rate.

Q. In other words, what you are saying is that there is a certain head of pressure —

A. A certain velocity of flow, actually.

Q. To your knowledge, are you generally familiar with what they call recycling of an oil well?

A. No, I am not.

Q. Do you know, in your organization, who has exact-ly explored the possibility, if anyone, of putting the water or else the gas back into the same hole that they took it out of?

A. No, I don't.

Q. Do you know of anyone in any of the other defendants that has explored this possibility?

A. No, — I think that this has not been explored further than these discussions in which we talked about the plant that might be needed to take this water out.

Q. And would you recapitulate the reasons, then, in your understanding, why this alternative was disregarded?

A. Because of the cost of the -- first of all, the plant which would remove the water, which is the one we said might be like half a million dollars, and then the fact that you have to build a storage capacity big enough to hold some large fraction of this water.

Q. Roughly, how big a storage capacity would have to be constructed to hold 500 M.m.s.c.f.?

MR. EARDLEY: Per what? Is that the total?

MR. LAMM: That was the total as listed by Dr. Aamodt, as the minimum amount of gas that would be flared.

A. To hold the gas?

Q. (By Mr. Lamm) My question was not the water, the question was, to hold the gas itself. ***

A. Something like maybe 450 million cubic feet.

Q. Relating that to something, a normal — is there a conventional gas tank that relates to storing of natural gas?

A. There are things which are built -- you know that float in water, and these are the biggest things that I have seen for storage of gas. Gas companies use those.

Q. Do you have any idea how much they would hold?

A. No, I don't.

Q. Do you have any other conventional --

A. We could make a guess as to the size of one if it would hold 450 million cubic feet. Take the cube root of that.

Q. Then the 450 million cubic feet is the figure that you have?

A. I'm sorry -- and that is only one cavity volume. This number that they have here let me think about that is about almost three cavity volumes, so the number is bigger than a trillion cubic feet.

Q. Would you estimate the size of it?

A. This number corresponds to more than a trillion cubic feet.

Q. But the possibilities are of the 500, and that's the possibilities we were working with. I am not trying to hold you, but trying to get an idea of about what storage capacity we would have to have.

A. About one and a half times this number of 450 million. The number then would be about 700 million cubic feet.

Q. And can you, in a structure size, estimate how big it would be?

A Yes, we can s ay what a cube would be. (Pause.) About a thousand-foot cube, a thousand feet on each side, a fifth of a mile.

MR. YANNACONE: What? No.

THE WITNESS: Cube root of .7 is very close to one. I said this number is about .7 times 10^9. The cube root of 10^9 is 10^3, and the cube root of .7 is not far from one. So it is just about a thousand foot on a side.

MR. YANNACONE: Where did you get the 10^9 from?

THE WITNESS: 450 million times 1-1/2.

Q. (By Mr. Lamm) Doctor, in your computations did you take into any consideration the possibility of the tritium being concentrated through the food chain or any other biological method?

A. I don't know the sense in which you are using "concentration." Do you mean relative to other hydrogen atoms, or do you mean the sense in which a certain concentration in water is changed to a different concentration in the animal?

Q. Well, let me say that in any of your definitions

A. Relative to hydrogen, we have no knowledge that there is any concentrated mechanism. That is the usual sense.

Q. To your knowledge, is there any scientific document with regard to concentration of tritium, in any of the senses?

A There are no reports that we were able to find that said that it was concentrated.

Q With regard to Operation Gasbuggy, were there various inquiries made specifically to this subject, in Operation Gasbuggy?

A. I don't know. I was not involved.

Q. Who in your organization would know?

A. I guess -- you want to know now specifically with respect to Gasbuggy?

Q. Yes, specifically with regard to Gasbuggy, specifically names.

A. I think that I would have to refer you to the people who come from Washington and who are quite knowledgeable in the field of tritium and its behavior, and I believe you do have some — do they have names of witnesses that —

MR. EARDLEY: I haven't been sworn yet, Doctor.

A. (Continued) You want a tritium expert for this. I may say something, that whatever mechanism of concentration exists is irrelevant as far as the protective measures 'that we are taking to protect people.

Q. (By Mr. Lamm) Why is that?

A. Because we are going to look at the concentrations at the point where it goes to people -- water, air, food. So how it got there is not pertinent to the hazard.

Q. How do you make your determination with regard to food, though, however, if you are not —

A. We take lots of samples of food that is locally grown, some from the stores, water supplies, deer.

Q. Dr. Aamodt, have you at any time or, to your knowledge, has the Atomic Energy Commission ever invited competitive bidding from any private waste disposal or radioactive disposal companies, with regard to Project Rulison?

A. No, sir.

Q. To your knowledge, have such estimates been asked for or made with regard to any other project that you know of in the Atomic Energy Commission?

A. Not to my knowledge, no.

FURTHER EXAMINATION BY MR. YANNACONE:

Q. Doctor, just so we keep the record straight, you don't hold yourself out as qualified to make evaluations of the biological effects of ionizing radiation, do you?

A. No, I do not.

Q. Now, to get down to something that you are apparently qualified to discuss, that is, the physical aspects of ionizing radiation, the water that you would extract from the natural gas by the process of burning -- that is heavy water, isn't it?

A. Not in the normal sense where, you know, normally it means deuterated water.

Q. But isn't tritiated water a little heavier than deuterated water?

A. It is not, in the concentrations that we would have here; it would really not be any heavier than normal water -- what you can measure.

Q. After tritiated water was concentrated by any one of the available processes, it would increase in concentration of tritium, wouldn't it?

A. I guess I don't understand the question.

Q. Let's withdraw it. After you burn the gas, do you know the relative ratio of volume of gas to volume of water produced after total combustion?

•A. It is not a very big fraction -- like two to three or something like this.

Q. It is a very small fraction, isn't it?

A. I was thinking of the water as a combustion product in the form of steam. *** It essentially all goes either to water or to carbon dioxide.

Q. And the ratio is what between the water and the carbon dioxide?

A. Let me have a piece of paper. (Pause.) Two-thirds is water, apparently.

Q. And, now, this two-thirds water, assuming the temperature were right, would be steam, right?

A. Right.

Q. So, we could say roughly that two-thirds of the volume of 450 million cubic feet of gas would wind up as water vapor or steam, right?

A. No, because there is a factor of 10 to 18 added during the burning process.

Q. 10 to 18 what?

A. Times the volume of gas that is burned. It takes air to support the combustion.

Q. The basic available product, though, to make the water is the hydrogen for the methane, right?

A. Plus oxygen.

Q. Yes, but the limiting product is the available hydrogen for the methane, right?

A. Right.

Q. So the limiting product is the hydrogen from the methane?

A. Right.

Q. Now, what is the molecular weight of methane?

A. Abou 16, I guess.

Q. What is the molecular weight of water?

A. About 18.

Q. So they are relatively close, aren't they?

A. Except that you get two waters, you see, for each methane. You get CH_4 and you make two H_2O.

Q. Be that as it may, we are still talking about 10^9 cubic feet, roughly, of water vapor, right?

A. No, he was talking about gas.

Q. I see -- 450 million cubic feet of gas?
A. And that is one cavity volume, and it is not standard cubic feet; that is equivalent to about 360 million standard cubic feet, I believe.

Q. So we are talking about one times 10^9 cubic feet, right?
A. Roughly, yes.

Q Okay. And we multiply that by 18 and we get 18 times 10 cubic feet, right, of steam?
A You multiply it usually by a thousand or -- oh, I'm sorry. I wouldn't find it appropriate to multiply it by 18, I don't think.

Q. What would you multiply it by?
A What do you want to do?

Q. I want to get the relative volume of steam.
A. It will be a minimum of ten times this number, the volume of the combustion products, and it may be as much as much as 18 times this number.

Q. So let's take 18 times 10 .
A. Okay.

Q. What is the ratio of steam to water when you reduce steam to water?
A. It is close to a thousand.

Q. So we are talking about 18 times 10 to the 6— 18 million cubic feet
A. Right.

Q. Now, of that water, some fraction of it will be essentially tritiated, right?
A. Right.

Q. Do you have any idea what fraction?
A. You divide it—well, I guess I could say — let's

see how we say this. In that assembly will be like two times 10 to the 23rd atoms which are tritiated.

Q. Convert that for me to cubic feet of tritiated water. I am assuming we are going to separate the tritiated water?

A. I believe that is less than a centimeter, is it not, cubic centimeter? It is a gram of tritium, you see. It makes one -- no, half a cubic centimeter of water.

Q. So, roughly, we are talking about half of that will be tritiated?

A. No, half a cubic centimeter.

Q. In that whole volume?

A. In that whole volume.

Q. Do you have any idea how big a volume a million or 18 million cubic feet of water is?

A. If you want to make a tank that would hold it, that was a cube, it's about —

Q. Maybe a hundred foot on a side, roughly?

A. Maybe three hundred.

Q. On one side?

A. A little less than that -- over two hundred. Two fifty perhaps on a side, and high.

Q. And the cavity that is under the ground is well within that size, isn't it?

A. Yes.

Q. So that the water could theoretically be run back into the hole from which the gas came, if it weren't for the head of pressure from the gas, right, or the flow rate of the gas, right?

A. Let me look at this. I don't know. We are talking about 18 million cubic feet.

Q. Yes.

A. Volume of the cavity is only about three million cubic feet.

Q. What about the fracture zone around it?

A. It doesn't have very much volume in it, you know.

Q. I thought it was 600 feet in diameter.

A. Cracks don't have a very big volume. They have a lot of surface, but —

Q. So a portion of it could be gotten rid of by pushing it back into the hole, and you do have two ways to get into the hole, don't you?

A. No, we only have one. *** They don't have any at the moment.

Q. Well, ultimately, if your project goes through as planned, you will enter through the experimental well, the R-E-X, right?

A. Yes.

Q. You will still have the direct cavity, the well with the Christmas tree on it now, that you originally fired the bomb off in it?

A. Yes -- unfortunately, plugged, though.

Q. Well, the other one was plugged, too.

A. You are proposing two reentries?

Q. Perhaps. That is one of the alternatives, isn't it?

A. It would take some study to see if this is so, but it would appear to be.

Q. Isn't it a fact, Doctor, that once you have the two holes, as it were, you can return the water through one and equalize the pressure of the gas through the other, and if necessary feed back some of the bled-off gas back into the water stream, to push the water down?

A. It would not seem impossible, provided you had the capability of extracting the water.

Q. Now, Doctor, to get back to the total amount of radiation, you are contemplating, in terms of for calculation purposes, releasing 10,000 curies of tritium and 1,000 curies of krypton at ground level or a little bit above ground level, in the region of Rulison, right?

A. Right.

Q. Do you know what the total background radiation level at the Rulison area is, or in the Rulison regional area is at this time, from all sources?

A. I could give you what is probably a close approximation. It might be within 20 milligrams or something like that.

Q. Doctor, I don't want it in rems, I want it in rads, roentgens, or curies per volume unit.

A. I don't have any such number in hand.

Q. But it is attainable and measurable, isn't it?

A. It wouldn't be pertinent, very likely.

Q. Doctor, that is for the Court to decide. I am asking you, it is measurable, isn't it?

A. It is a very expensive operation. I don't know that it's ever been done.

Q. Oh, come now, Doctor, isn't it a fact that for years the Atomic Energy Commission reported background during the fallout period, in terms of total background radiation, alpha, beta, gamma, any given area, from all sources?

A. But you --

Q. Isn't that a fact, Doctor?

A. Not to my understanding, with the kind of definition that you want.

Q. Doctor, isn't it a fact that the Atomic Energy Commission for years, during the period of atmospheric testing, reported at regular intervals from stations all over the country the total background ionizing radiation level, reported in terms of total alpha radiation, total beta radiation, total gamma radiation received -- isn't that a fact?

A. I thought you asked about an area. It is not a fact, as far as I know, that they ever reported what the radiation, for instance, in a square mile was, for instance,

Q. Come now, didn't they report it at a monitoring station in one part—

A. They can report it at one point.

Q. Do you have the total background from all sources at any monitoring point within the region of Project Rulison?

A. For people, for air?

Q. Come now, Doctor, you are measuring total background radiation, that is, the ambient radiation at the site of the monitor.

A. We have a detector sitting right at ground zero that's been measuring background for a long time.

Q. What has it been measuring? What is it sensitive to?

A. It is a scintillation type detector, and it is sensitive to gamma rays.

Q. Is that all?

A. And penetrating beta rays, if they --

Q. What kind of a crystal does your scintillation counter have?

A. Sodium iodide.

Q. And what energy level electrons is that capable of detecting?

A. I would think it would detect -- it depends on the thickness of the container. I would expect it to respond to one-million-volt electrons.

Q. Is it sensitive to lower-level electrons?

A. If they are created inside the crystal.

Q. By secondary radiation?

A. I guess you could call it a Compton scattering and so on.

Q. It isn't sensitive to alpha particles as such, is it?

A. Not if they are on the outside, they can't penetrate the —

Q. Again, you could only measure alpha if you could get some secondary scattering within the crystal, right?

A. Alpha doesn't ordinarily give rise to anything measurable.

Q. What kind of a window does your crystal have?

A. I am not very familiar with it. I am familiar with these things as a general class, and the window might be perhaps a sixteenth inch of glass, something like that.

Q. And that is pretty effective for stopping most low level beta rays, isn't it?

A. Very much.

Q. And it is almost totally effective in stopping alpha particles, isn't it?

A. (The witness nodded affirmatively.)

Q. Now, Doctor, it is a fact, then, you have no facility, even at ground zero, for measuring alpha radiation and beta radiation in the vicinity, right?
A. I don't think that is correct.

Q. Oh? Tell us about it.
A. The Eberlein people have a trailer which has been in position at ground zero, which is capable of measuring tritium in water, tritium in air, in gas.

Q. Come now, Doctor, please -- I asked you one question. Do you have a facility anywhere in the Rulison region capable of measuring the total background radiation from sources of alpha, beta, or gamma radiation, at all energy levels for those three phenomena?
A. I am not aware of any such instrument existing.

Q. I didn't say a single instrument.
A. Oh, you didn't?

Q. You know as well as I do, Doctor, that you can't do that with a single instrument, isn't that correct?
A. I think that is correct.

Q. And isn't it standard operating procedure in the field to measure each of these with three different devices?
A. Correct.

Q. Do you have those three different devices any- where within the Project Rulison region?
A. At the moment?

Q. Yes.
A. We have had, and we will again.

MR. SEARLS: Why can't we have this questioning in a more orderly way?
MR. YANNACONE: We will take it from the top.

Q. (By Mr. Yannacone) Do you have a device at present any- where within the Rulison region for the measurement of alpha radiation as background? Yes or no?

A. I expect that there is, but I'm not sure.

Q. You don't know, do you?

A. I don't know. We have had a monitor on site for some time.

Q. Do you have any figures, Doctor, as to background alpha radiation in the Rulison region?

A. I do not.

Q. Well, Doctor, if you have had a device there, wouldn't it have a reading? Wouldn't someone make a reading on it, Doctor?

A. Such measurements have been made in that region.

Q. They have. Where are they reported, Doctor?

A. I think that we could get them and give them to you, if you like. My understanding is that they have been background at all times.

Q. What do you mean by "background," Doctor?

A. It means that they were the same after the shot as they were before.

Q. Oh, come now, Doctor, I have been asking you about the absolute radiation level, the total amount of ionizing radiation present from all sources, measured as alpha, beta, or gamma radiation, within the Rulison region. That's all I am trying to find out from you, Doctor, either what it is or where the information is contained, if it is known at all.

A. I think we could get that information for you.

Q. Do you have it, or don't you have it?

A. I don't have it in my pocket.

Q. Well, Doctor, don't you think you have to know the total background radiation, possible exposure to people in a given area from all sources, before you can compute the total amount of radiation exposure they can be subjected to from any source?

A. You are asking me if I am making up new criteria for protection of people?

Q. No, Doctor. Mr. Reporter, please read my question. ***

A. Is this expressed in any criteria that you know of?

Q. Doctor, I am the lawyer. My job is asking questions. You are the scientist, and your job is answering questions. Please read my question back and ask the doctor to answer it.

(Question read.)

Q. (By Mr. Yannacone) Can you answer that question?

A. Yes, I can answer your question. I think the answer is no.

Q. Now, Doctor, isn't it a fact that any radionuclides released as a result of the flaring at Project Rulison, will increase the total background radiation level within the Rulison region?

A. It is a hypothetical question. You understand that.

Q. No, Doctor, I am not asking you a hypothetical question. I am asking you a simple question; First tell me if you can answer it. Can you tell me whether the release of any ionizing radiation as a result of the flaring of Project Rulison will increase the background radiation level from all sources in the Rulison region.

A. It is not necessarily true.

Q. Doctor, tell me a physical process whereby it won't be true.

A. Well, if you measured that radiation today and if you have some fallout from the Chinese tests, for instance, in the area, and it is decaying, then when you add this radiation, you may measure it again and now you find a lower value that you have now.

Q. Doctor, I am not talking about measurements, I am talking about absolutes. Isn't it a fact that the release of any ionizing radiation as a result of the flaring of Project Rulison will increase the background level over what it was at the moment the material was released?

A. Yes, sir.

MR. YANNACONE: Thank you, Doctor. No further questions.